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Integrated management of arthropod pests of veterinary importance: Recent up-dates on unconventional but feasible measures

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ABSTRACT

Prevalence of vector-borne diseases is on a rising trend. Global warming is one of the reasons for this exceptional rise. World Health Organization (WHO) declared "Protect yourself from vector- borne diseases" "Small bite : Big threat" as theme of the year on the occasion of World Health Day (7 April 2014). It is the need of the hour to combat the vectors and protect our animals from vector flies and pests. The best way for combating the vectors is implementation of integrated pest management (IPM) or integrated vector management (IVM) practices suitable to local conditions. One of the objectives of such control programmes is to control the pest/vector population with least damage to environment by using biocontrol agents and if necessary use of chemical pesticides. Present review has attempted to concise all such information pertaining to recent developments in the area of IPM. The other objective of the paper is to highlight and promote the research needed to be undertaken in the area of vector epidemics, biology and biological control.

Key words: Arthropod pests, Integrated pest management, IPM, Unconventional Feasible measures

Broadly, species of arthropods infesting livestock are called ecto-parasites, which are grouped into flies (biting, non-biting), fleas, lice (biting, sucking), ticks (soft, hard) and mites (burrowing, non-burrowing and follicular). These ecto-parasites have impact on health of livestock and poultry due to (a) annoyance, worries and nuisance through painful bite leading to psychological disturbances and hence decrease in production, (b) potent mechanical and biological vectors of bacterial, viral, protozoan and rickettsial diseases may result in death, and (c) hazardous effects acquired through application of chemical pesticides used for their control resulting in intoxication, disturbances in growth, nervous symptoms and several health hazards. During 1939–1975 (Era of insecticides with the discovery of DDT (di- chloro- di- phenyl- trichloroethane) by Paul Muller in 1939) insecticides were used indiscriminately, which paved way for the entry of insecticides in food chain and residue formation in crops and animals tissues. Such routine and reckless use resulted in the resistance and resurgence of pests leading to an emergence of another era of integrated pest management (IPM) from 1975 onwards. Initially, very few physical means and biological agents were inducted in the programme. But with advancement in research many biological agents which were not considered as conventional were investigated and now occupying the role in IPM of pests of livestock. Present paper is intended to take review of all such unconventional but feasible methods which can be used in IPM programme very conveniently and effectively. The theme of the present paper can be explained through the part of FAO definition of biological control "The rationale behind replacing conventional pesticides with bio-pesticides is that the latter is more likely to be selective and biodegradable" (http://www.fao.org/biotech). Through this article author wishes to put on record that, over conventional chemical control, many options in the form of biological and physical control are becoming popular and manifesting good results on the field for IPM of livestock pests, though these are not routinely used and thus are considered as unconventional. As unconventional methods are feasible, cost effective, eco-friendly, user friendly and biodegradable, thus need extensive research and rigorous extension activities for making them conventional like chemical pesticides.

What is the concept of integrated pest management (IPM)?

It means integrating available pest control methods to achieve effective, economical and sustainable combination of chemical, biological and cultural control. In IPM programme chemical pesticides are used as the last resort due to their increased application cost and hazards associated with their use. In IPM, environmental consideration is the most important and expected to advise

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the use of eco-friendly benign pest control chemicals, which are effective against target species and create minimum adverse effect on non-target species. According to A Cornell and Penn State Cooperative Extension publication, Pest Management recommendations by Geden and Rutz (2010) for dairy cattle, included insecticide use as a single control tactic in the management of cattle pests in the past. Modern dairy producers are weaving careful use of pesticides into integrated pest management (IPM) programs and not dependent on the use of single tactic. IPM programs seek to maximize the effectiveness of pest control actions while conserving beneficial insects and minimizing pesticide use. The cornerstone of effective IPM is the correct pest identification along with accurate and timely pest monitoring. Other components are various combinations of cultural, biological, and chemical control practices designed to keep pest populations below economically injurious levels though chemical control, which forms last resort and part of IPM. The single tactical conventional approach used in the past has aggravated insecticide resistance problems in pest populations and inadvertently responsible for destruction of natural enemies of the target species. Hence, more recently the use of unconventional, feasible and cost effective approach through cultural and biological control is gaining popularity. Present review is intended to take stock of the recently developing and in-use cultural and biological control methods against livestock pests.

Following facts necessitates and compels adoption of biological and other means of IPM by minimizing the use of chemicals in the modern era of global warming

1. The increasing trend of people towards pesticide free food, meat, milk, pork etc (in several countries is stimulating the growing market of 'organic' food). With increasing concern about environmental safety and human health.
2. Bio-control through BCAs (biological control agents) is self perpetuating and self propagating and their recycling for many years, offers permanent control in the eco-system. The protection of our eco-system is of paramount importance which can be achieved by use of bio-pesticides and IPM over conventional (chemical) control.
3. "IPM has been a high priority thrust area for last 2 decades for the Government of India for sustainable and eco-safe agriculture. It has acquired further importance keeping in view of India becoming signatory to WTO" (Remark of Plant protection Advisor, Government of India in 2002 (Singhal and Sharma 2004).
4. Survey reports from India revealed that all food products such as cereals, pulses, vegetables, fruits, animal products, vegetable oils, milk, milk products, spices and honey contain the pesticide residues (Kathpal and Kumar 2000, Singh and Dhaliwal 2000).
5. Biological control agents have the capability to search their prey (pest), perhaps it is a possible reason that biological control is successful for management of pests exhibiting resistant to chemical pesticides (Dhaliwal and Arora 2006).
6. The increasing costs of chemical control.
7. Biological control of an individual pest species can be best achieved through implementation of package of integrated pest management (IPM) module.
8. As per Peter *et al.* (2005), to continue the production of the livestock in a sustainable fashion, it is suggested that what was used in the past will continue to form the mainstay of future control. For the foreseeable future, we must conserve what we have, and use it in combination with all the principles of integrated pest management, namely strategic and focused treatments of animals, environmental control of breeding sites, disease management (including the principles of enzootic stability), and resistant breeds.

Historical background (few important landmark events) to recent the up-dates of Biological Control: (History taken from *Biological Control of Pests, ENTO 675, UH-Manoa, Fall 2000, M. W. Johnson Web page* nature.berkeley.edu/biocon/./6-11%20BC%20History.pdf)

Early period: (A) 200 AD to 1200 AD: BC agents were used in augmentation.

300 AD. Chinese were the first to use natural enemies to control insect pests. Nests of the ant *Oecophylla smaragdina* were sold near Canton for use in control of citrus insect pests.

1200 AD. Ants were used for the control of date palm pests in Yemen.

(B) *1300 AD to 1799 AD:* BC was just beginning to be recognized.

1700. In the late 1700, birds were transported internationally for insect control.

1706. Vallisnieri interpreted the phenomenon of insect parasitism (parasitoid).

1726. The first insect pathogen *Cordyceps* fungus on a noctuid was recognized by de Reaumur.

1776. Control of bedbug, *Cimex lectularius*, was successfully accomplished by releases of the predatory pentatomid *Picromerus bidens* in Europe.

(C) *1800 A.D. to 1849 A.D:* During this period advances were made in Europe.

1837. Kollar (Austria) put forth the concept of "natural control".

1838. Verhulst described the logistic growth equation but this idea remained dormant until 1920 when rediscovered by Pearl and expressed the idea of "environmental resistance".

(D) *1850 to 1887:* During this time the focus on BC switched to the United States.

1863. First practical attempt at BC of weeds.

1882. *Trichogramma* sp. (egg parasites) were shipped from the U.S. to Canada for control of lepidopterous pests.

1883. USDA imported *Apanteles glomeratus* from

England for control of *P. rapae* (the imported cabbageworm). First intercontinental shipment of parasites.

The Intermediate Period: 1888 to 1955

1888 to 1889: The Cottony Cushion Scale Project.

1900 to 1930: New faces and more BC projects.

1911. Berliner *Bacillus thuringiensis* as causative agent of bacterial disease flourmoth.

1919. USDA laboratory for biological control established in France in 1919.

1927. The Imperial Bureau of Entomology created the Farnham House Laboratory for BC work in England.

(E) *1930 to 1955:* Expansion and decline of BC

1930–40. There was a peak in BC activity in the world with 57 different natural enemies established at various places.

1944 World War II caused a sharp drop in BC activity due to the production of relatively inexpensive synthetic organic insecticides. Entomological research switched predominantly to pesticide research.

1947. The Commonwealth Bureau of Biological Control was established from the Imperial Parasite Service. In 1951 the name was changed to the Commonwealth Institute for Biological Control (CIBC). Headquarters are currently in Trinidad, West Indies.

1955. The Commission Internationale de Lutte Biologique contre les Enemis des Cultures (CILB) was established. This is a worldwide organization with headquarters in Zurich, Switzerland.

1962. The CILB changed its name to the Organisation Internationale de Lutte Biologique contre les Animaux et les Plants Nuisibles. This organization is also known as the International Organization for Biological Control (IOBC). It initiated the publication of the journal, viz. *Entomophaga* in 1956, devoted to BC of arthropod pests and weed species.

The Modern Period: 1957 to Present day

1959. Vern Stern *et al.* (1959) conceived the idea of economic injury level (EIL) and economic threshold (ETL) which would permit growers to make informed decisions on when they needed to apply control tactics in their cropping systems and therefore eliminated the need for scheduled pesticide treatments.

1962. Interest developed nationwide in ecology and the environment after 1962 with the publishing of the Rachel Carson's book "Silent Spring", which helped to stimulate the implementation of the concept of integrated pest management (IPM) in the late 1960's, and biological control was seen as a core component of IPM. More emphasis was placed on conservation BC than classical BC.

1964. Paul DeBach and Evert I. Schliner (Division of Biological Control, University of California, Riverside) published and edited volume titled *Biological Control of Insect Pests and Weeds*, which became a major reference source for the biological control community. This was basically a California based book with international application.

In some areas in the USA (e.g., California, North Carolina, Kansas, Texas), IPM scouting was commercialized in the 1970's and natural enemies were relied upon to suppress pests in crops such as cotton, alfalfa, citrus, soybeans, and other crops.

1970's and 1980's. Brian Croft and Marjorie Hoy made impacts by using pesticide resistant natural enemies in cropping systems.

1983. Frank Howarth published his landmark paper titled "Biological Control: Panacea or Pandora's Box" and significantly impacted classical BC efforts.

1990's. Two additional biological control journals appeared, *Biological Control - Theory and Application in Pest Management* (Academic Press) and *Biocontrol Science and Technology* (Carfax Publishing). Additionally, *Entomophaga* changed its name to *Biocontrol* in 1997.

1990 till present-Era of herbal and biological control through microbes, fungus, virus, nematodes as BCAs.

The purpose of citing brief history of BC is to stress upon the importance of BC from time immemorial. Only a brief period of 50 years (1940–1990) was dominated by chemical control. However chemical control adopted has many advantages during that critical period (1940–1990), such as to overcome food scarcity, supply of food to increasing human population, unavailability of BCAs etc.

Concept of biological control

It is a sub-discipline of applied ecology. To adequately practice it, one should have a firm understanding of population and behavioural ecology. Without systematic and proper identification of pests and their associated natural enemies, biological control as a science would fail to function (nature.berkeley.edu/biocon/./6-11%20BC%20History.pdf).

H. S. Smith (1919) first used the term biological control to signify the use of natural enemies (whether introduced or otherwise manipulated) to control insect pests. DeBach (1964) distinguished the term natural control and biological control. Natural control is the maintenance of a more or less fluctuating population density of an organism within certain definable upper and lower limits over a period of time by the actions of abiotic and/or biotic environmental factors. Biological control (ecological viewpoint) is "the action of parasites, predators, or pathogens in maintaining another organism's population density at a lower average that would occur in their absence". As per van den Bosch *et al.* (1982), applied biological control is defined as the manipulation of natural enemies by man to control pests, and natural biological control is a control that occurs without man's intervention.

According to Wikipedia (2012) biological control is a method of controlling pests (including insects, mites, weeds and plant diseases) using other living organisms. It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role. It can be an important component of (IPM) programs.

Applied biological control has 3 major categories/ parts (nature.berkeley.edu/biocon/./6-11%20BC%20History.pdf)

Classical biological control (*importation*)*:* Involves the introduction of a pest's natural enemies to a new location where they do not occur naturally. The process of importation involves determining the origin of the introduced pest and then collecting appropriate natural enemies associated with the pest or closely related species. Selected natural enemies are then passed through a rigorous assessment, testing and quarantine process, to ensure that they will work and that no unwanted organisms (such as hyper parasitoids) are introduced. If these procedures are passed, the selected natural enemies are mass produced and then released. Follow-up studies are conducted to determine the successful establishment of natural enemy at the site of release, and to assess the long-term benefit of its presence. It is long lasting and inexpensive except the initial costs of collection, importation and rearing.

Augmentation of natural enemies: It involves the supplemental release of natural enemies for boosting or for increasing the populations or beneficial effects of the naturally occurring population. Relatively few natural enemies may be released at a critical time of the season (inoculative release) or millions may be released (innundative release).

Conservation of natural enemies: The premeditated actions purposely taken to protect and maintain or conserve the populations of existing natural enemies in an environment. Natural enemies are already adapted to the habitat and to the target pest, and their conservation can be simple and cost-effective.

Types of natural enemies used as BCAs

Pathogens: A microorganism that lives and feeds (parasitically) on or in a larger host organism and thereby causes injury to it. Examples viruses, bacteria (and their toxins), protozoa, fungi, nematodes, microsporidian *Thelokomia opacita* for control of Tabanids, mosquitoes, midges, Simulids (Dylko 1979).

Parasitoids: A parasitic insect that lives in or on and eventually kills a larger host insect (or other arthropod). Wasps: *Splalangia cameroni* are the pathogens for house flies.

Predators: An animal that feeds upon other animals (prey) that are either smaller or weaker than itself, e.g. *Poecilia rectculata* (guppy fishes) is a larvivorous fish for the control of mosquitoes (Ansari and Sharma 1993, Hossain *et al.* 1997, Wang *et al.* 2000) and for *Culicoides* spp (Narladkar 2003).

What is the concept of bio-pesticide?

EPA definition: Biopesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered biopesticides. Biopesticides are of following types:

1. *Microbial pesticides:* Consist of a microorganism (e.g. a bacterium, fungus, virus or protozoan) as their active ingredient. Microbial pesticides can control many different kinds of pests, although each separate active ingredient is relatively specific for its target pest(s).
2. Plant-incorporated-protectants (PIPs) are pesticidal substances that plants produce from genetic material that has been added to the plant. For example, scientists can take the gene for a specific Bt pesticidal protein, and introduce the gene into the plant's genetic material. Then the plant manufactures the pesticidal protein that controls the pest when it feeds on the plant. http://www.epa.gov/pesticides/biopesticides.

According to Peter *et al.* (2005) effective control of ecto-parasites in future will not only be determined by the effectiveness of a particular method or combination of methods, but particular method shall have sustainability with local issues and these issues will be

1. *Environmental sustainability:* The developed method shall not have any adverse effect or damage to the environment. Similarly they shall deem fit according to rules and regulations formed for protection of environment by the local governing bodies of a particular nation. Similarly such developed method or BCA shall be friendly to other fauna of beneficial insects.
2. *Socio-economic sustainability:* In a particular locality adaptation of any new method of pest control will largely depend on the factors such as (a) cost, (b) willingness to pay, and (c) availability of the control method. Role of Government and legislation is very crucial.
3. *Technical sustainability:* The developed method should be technically competent enough to take care of the pest in question? Similarly, it also involves the strict follow up of technical details by the farmers in terms of dose/concentration, correct time of application or season, correct ways to use, exact stage of the pest against which it is to be used, storage etc.

All the 3 issues if successfully tackled then success of any BCAs or method of control can be achieved to the fullest extent.

The recent updates on unconventional and feasible methods of control of pests of veterinary importance are summarized in Table 1.

Mode of action of BCAs and herbal pesticides

Botanicals: Essential oils from herbs are known to have insecticidal properties, and the mode of action may be through the acetylcholinesterase inhibition and

Table 1. Summary of recent up-dates on unconventional and feasible methods of control of pests of veterinary importance

Pest of veterinary importance	Integrated pest management measures including physical, cultural and biological control through herbal/microbial/fungal and any other
Culicoides midges	*Physical:* Provision of net shed (Narladkar and Shivpuje 2012c, Calvate *et al.* 2010); Breeding habit management (Narladkar and Shivpuje 2013a) Forecasting on the basis of climatic changes and seasonal variation studies: Prediction models based on climatic data and seasonal variation studies (Narladkar *et al.* 2003c, 2006a, 2006b, Narladkar 2013c) *Biological:* i. *Metarhizium anisopliae* (Ansari *et al.* 2011,Narladkar *et al.* 2012d) ii. *B. cereus* (Dylko 1979, Narladkar 2012a, Narladkar *et al.* 2014), iii. *B. thuringiensis* var *israelensis* and *B. spharicus* (Narladkar 2003a) iv. Pathogenic microsporidian *Thelokomia opacita* (Dylko 1979) v. Predacious guppy fishes: *Poecilia recticulata* (Narladkar 2003a, 2008a) *Herbal:* i. Herbal oils: Neem oil and Karanj oil (Narladkar 2007, Narladkar and Shivpuje 2012b), herbal fly repellants like neem and eucalyptus oil (Narladkar *et al.* 2011d) *Integrated management of* Culicoides *spp:* Integrating physical, biological and BCA for control (Narladkar *et al.* 2003b, 2006 b, Narladkar 2004, 2005, 2008b, 2009, 2010a, 2011a, 2012g, 2013d)
Boophilus microplus	*Physical:* Process involving burning of tick eggs in the cattle shed for annihilation of breeding places, to be undertaken three consecutive times at weekly interval in a season (Narladkar 2012a, Narladkar *et al.* 2010b) *Biological:* (a) *Verticillium lecanii* and *Beauveria bassiana* strain LBBb-14 (applied on calves body) (Rijo 1994). (b) *In vitro* efficacy of *B. bassiana* in engorged females (Bittencourt *et al.* 1997) (c) Strain Ma-z4 of *M. anisopliae* and strain Bb-1 of *Beauveria bassiana* (applied directly to animal body) (Lopez *et al.* 1998). (d) *M. anisopliae* and *Beauveria bassiana* and use of three herbal oils— neem oil (*Azadirachta indica*), karanj oil (*Pongamia pinata*) and Nilgiri oil (*Eucalyptus globulus*) (Narladkar *et al.* 2012b, 2012e)
Hyalomma and *Boophilus*	*Biological:* Alcoholic extracts of sitaphal (*Annona squamosa*) and neem (*Azadirachta indica*) against different life stages (Ghosh *et al.* 2007)
Ticks	*Physical:* Caulking of the cracks and crevices on walls of the animal's sheds by slow burning over a period of one or two days (Muhammad *et al.* 2008) *Biological: Metarhizium anisopliae* and *Beauveria bassiana* (Samish *et al.* 2004), Pheromones used by ticks for aggregation and mating can be artificially used in combination with acaricides (Sonenshine 1993)
Rhipicephalus appendiculatus	*Biological: M. anisopliae* and *Beauveria bassiana* (Mwangi *et al.* 1995)
Dermacentor variabilis and *Amblyomma americanum*	*Biological: B. bassiana* used in the laboratory and on the field (Cradock 2005).
Hyalomma anatolicum anatolicum and *H. marginatum*	*Biological:* Two Iranian strains of *Beauveria bassiana* (*Beauveria bassiana* 5197 and *Beauveria bassiana* Evin) (Abdigoudarzi *et al.* 2009)
Simulium flies	*Physical:* Identifying and targeting areas of winter harborage within the dispersal range of black flies *Biological: Bacillus thuringiensis* serovar *israelensis* (Lacey *et al.* 1982, Molloy 1992, Carlos *et al.* 2003, Tubbs 2011), *B. cereus* and use of microsporidian *Thelokomia opacita* (Dylko 1979).
Musca flies	*Physical:* (a) According to A Cornell Penn state IPM publication, spreading manure and bedding as thinly as possible will help to ensure that it dries out quickly and on the basis which, waste management is the first line of defense in developing an effective fly management programme was suggested.

	(b) Wet straw should not be allowed to pile up in or near buildings, since, straw is one of the best fly breeding materials (c) Augmentative biological control (periodic release of parasitoids during winter and spring, and following manure removal) using insectary. (d) Schmidtmann (1991) calf hutched bedding with materials such as woodchips, ground corncobs, or sawdust due to which house fly and stable fly development was suppressed. (e) Geden *et al.* (1992) proposed to clean out the calf pens on a weekly basis. Lazarus *et al.* (1989): It is economically feasible to reduce insecticide application on dairy farms for house fly control if manure was removed from the barns every 7 days. (f) Morgan *et al.* (1972): significantly reduced fly populations by simply hanging doorway curtains in the entrance way. When cows enter, house flies are brushed from the backs and flanks of the animal
	Biological (a) Histerid beetles and macrochelid mites feed ravenously on fly eggs and young larvae (Kaufman *et al.* 2002, Achiano and Giliomee 2005). (b) Larvae of fly genus *Hydrotaea* (*Ophyra*) *aenescens* are facultative predators of house fly larvae (Nolan and Kissam 1987, Geden *et al.* 1988, Hogsette and Jacobs 2003). (c) Entomopathogenic nematodes such as *Steinernema* and *Heterorhabditis* spp. and their associated symbionts are virulent for fly larvae in certain substrates (e.g. cow manure mixed with soil) (Taylor *et al.* 1998, Geden 2012), (d) Fungal pathogen, *Beauveria bassiana* (Steinkraus *et al.* 1990, Mwamburi *et al.* 2011a) (e) *Entomophthora muscae* and *E. schizophorae* (Kalsbeek *et al.* 2001). (f) *B. bassiana*, some strains of *M. anisopliae* have been demonstrated to have superior performance against both adult and larval house flies (Mishra *et al.* 2011, Sharififard *et al.* 2011). (g) *Spalangia cameroni* and *Muscidifurax raptor wasps* (Geden *et al.* 1995, Kaufman *et al.* 2005, Nielsen *et al.* 2005). (h) Fan *et al.* (2010) fused a *Bombyx mori* chitinase to a protease in *B. bassiana.* The chimeric pathogen was substantially more virulent than the wild-type, presumably because of improved binding and delivery of proteases to the target cuticle. (i) Promising new strains have been identified *Bt* in Korea (Choi *et al.* 2000, Oh *et al.* 2004). Labib and Rady (2001) reported that *Bt* was more effective for fly control on Egyptian poultry farms when it was added to the birds' food than when it was applied directly to the manure. Similar results were noted for *B. thuringiensis* subsp. *israelensis* (*Bti*) (Mwamburi *et al.* 2011b). (j) Salivary gland hypertrophy virus of house flies (MdSGHV) (Coler *et al.* 1993, Garcia *et al.* 2009, Lietze *et al.* 2010). (k) Essential oils with substantial amounts of 1,8-cineole, pulegone, limonene, and menthol have high toxicity against fly adults. Combinations of house fly-active oils (e.g. rosemary, peppermint, pennyroyal mint, blue gum, bay laurel) could be more effective as synergistic agents (Kumar *et al.* 2011, Geden 2012).
Stomoxys flies	*Physical:* (a) Sanitation: Immature flies (eggs, larvae, pupae) live in manure, moist hay, spilled silage, wet grain, etc., for 10 to 21days. Hence, removing and spreading fly breeding materials weekly helps to break the cycle. Waste management is therefore the first line of defense in developing an effective fly management program (According to A Cornell Penn state IPM publication), *Biological:* (a) BC of *M. domestica* and *S. calcitrans* (Diptera: Muscidae) by means of inundative releases of *Spalangia cameroni* was the predominant parasitoid to emerge from exposed house fly pupae, but from mid summer onwards *Muscidifurax raptor* Girault and Sanders (Hymenoptera: Pteromalidae) was also quite common (Skovgård and Nachman 2004, Birkemoe *et al.* 2009) (b) *Metarhizium anisopliae* to eggs and immature stages (Moraes *et al.* 2008)
Haematobia irritans	*Biological:* (a) Fungi such as *B. bassiana* and *M. anisopliae* may have the potential for controlling populations of adult horn flies by causing mortality in a short time (Lohmeyer and Miller 2006) (b) The family Staphylinidae contains the most important predators of dung-breeding flies because

	of their diversity and high populations in pastures. Both the adult and larval stages of staphylinids prey on immature stages of flies in dung deposits and several species have been documented as effective predators (Thomas and Morgan 1972, Roth *et al.* 1983, Thomas *et al.* 1983, Hunter *et al.* 1989)
Phlebotomus sergenti	*Physical:* Sand flies breed inside caves that are also home to rock hyraxes and several rodent species, covered caves, concealed cracks in the rocky ledges close by, man-made support walls constructed with large boulders. Understanding of sand fly larval ecology an important key in IPM (Moncaz *et al.* 2012)
Mosquitoes	*Physical:* (i) mosquito net (UNICEF 2000) (ii) "Bio environmental model" Dua *et al.* (1997) for control of Industrial malaria which includes: (a) Filling of pits, low lying areas and ditches with coal ash from power station (b) Construction of stand post and proper drainage (c) Mosquito proofing of overhead tanks and proper sewage system (d) Application of expanded polystyrene beads to underground tanks, leaking sluice valve chambers and blocking of sewage manholes (e) Application of bio-larvicides to water accumulated bodies (f) Larviparous fish Guppy (*Poecilia reticulata* and *Gambusia affins*) to storm water drains. *Biological:* (a) *Metarhizium anisopliae* and *Beauveria bassiana* (Bukhari *et al.* 2011) (b) *Bacillus cereus* as natural facultative pathogen of *Anopheles subpictus* (Chatterjee *et al.* 2010) (c) *Bacillus thuringiensis* var *israelensis* (Srivastava *et al.* 1996) (d) *B. thuringiensis* var *israelensis* and *B. sphericus* against mosquitoes in India (Behari 1990) (e) Use of pathogenic microsporidian *Thelokomia opacita* (Dylko 1979) (f) Predacious fishes: *Poecilia rectculata* (guppy fishes) (Ansari and Sharma 1993, Hossain *et al.* 1997, Wang *et al.* 2000)
Tabanus	*Physical:* Maximum number of bites of insect pests can be prevented by keeping the animals in the shed during bright sunshine hours of day during peak fly season. Use of breeding habbit information data (Narladkar and Patil 2012f) *Biological:* *B. cereus* and pathogenic microsporidian *Thelokomia opacita* (Dylko 1979).
Lice	*Biological:* (a) The fungus *Trenomyces histophtorus* (order Laboulbeniales) used against *Haematopinus eurysternus*, *Linognathus vituli*, *Bovicola Bovis* and against chicken lice (Meola and DeVaney 1976, DeVaney *et al.* 1988) (b) Sheep wool derived strains of *B. thuringiensis* were effective against *Damalinia ovis* and *B. bovis*
Fleas	*Physical:* According to Beck and Pfister (2004) adult fleas and their life cycle stages must be covered equally. Flea control needs to be carried out on the animal and in its environment simultaneously. (a) Flea control agents must be used therapeutically, prophylactically, regularly, on a long-term basis and consistently for all the animals in a household (b) (S)-Methoprene (IGR), which has a very low level of toxicity to mammals, and does not irritate skin or mucous membrane and is not toxic to fish (Franc 2003) (c) Adulticides and growth regulators may be combined.
Mites	*Biological:* *Psoroptes mites* with the fungus *Metarhizium anisopliae* (Smith *et al.* 2000, Brooks and Wall 2001) Herbal pesticides (Narladkar *et al.* 2011b, c)
Myiasis causing flies	*Biological:* Using entomopathogenic fungi, *Bacillus thuringiensis*, and phoretic mites (Hall and Wall 1995, Mazyad and Raheem 2001)

octopaminergic effects (Isman 2000) and by way of attraction/ repellency and contact toxicity (Koul *et al.*2008). Chemical compounds containing specific active molecules against which insect can target and can immediately develop the resistance; but the herbal or natural oils holding good activity against insects without showing any evidence of resistance. These have been used since time immemorial, over 100 years (Howard 1911). The reason could be that, these are complexes of many biologically active constituents including terpenes, acyclic monoterpene alcohols, monocyclic alcohols, aliphatic aldehydes, aromatic phenols, monocyclic ketones, bicyclic monoterpenic ketones, acids, and esters (Koul *et al.* 2008). Complex interactions may occur among major and minor constituents in an unforeseen manner that enhances insecticidal activity. Addition of piperonyl butoxide can reduce the LC_{50} of essential oils and their individual constituents by several orders of magnitude (Waliwitiya *et al.* 2008).

Effects of neem on insects: Manifested at different levels and in different ways.

Insect growth regulation: When the neem components, especially azadirachtin, enter the body of the larva, the activity of ecdysone is suppressed and the larva fails to moult, remains in the larval stage and ultimately dies. In case, concentration of azadirachtin is lower, then also adult emergence from the pupa will be 100% malformed, and it will be absolutely sterile.

Feeding deterrent: If the surface over which they feed (drainage channel for larvae and animal body for adult insect) is treated with a neem product, because of the presence of azadirachtin, salanin and melandriol, there will be an anti-peristaltic wave in the alimentary canal which produces something similar to a vomiting sensation in the insect, and hence, it does not feed on the neem-treated surface. Its ability to swallow is also blocked.

Oviposition deterrent: Neem controls pests by preventing the females from depositing eggs. There are also well established modes of action such as (a) formation of chitin or the hard part covering of the insect exoskeleton is inhibited; (b) mating as well as sexual communication are disrupted; (c) larvae and adults of insects are repelled; (d) sterilization of adults, and (e) larvae and adults are poisoned. Neem products have to be ingested by the insects to prove more effective. Those insects which feed on plant tissues, ultimately easily succumb.

Fungus: Entomopathogenic fungi are widely distributed throughout the fungal kingdom, although the majority occurs in the *Deuteromycotina* and *Zygomycotina* families of which *Metarbizium anisopliae* and *Beauveria bassiana* has wide host range and hence these are being exploited as fungal biopesticide on large scale. The mode of action on generalized line of fungus against insects was narrated by Goettel and Inglis (1997). According to them, the most common route of host invasion is through the external integument, although infection through the digestive tract is also possible. Conidia attach to the cuticle, germinate, and penetrate the cuticle. Once in the hemocoel, the mycelium grows throughout the host, forming hyphal bodies called blastospores. Death of the insect is often due to combination of the action of fungal toxins, physical obstruction of blood circulation, nutrient depletion and/or invasion of organs. After the host has died, hyphae usually emerge from the cadaver and, under suitable abiotical conditions conidia are produced on the exterior of the host. These are then dispersed by wind or water.

The mode of action of 2 fungi has been discussed in detail by Scholte *et al.* (2004).

Beauveria bassiana: Conidial dry powder when poured on water surface of breeding sites of mosquitoes, conidia being hydrophobic, thus keep on floating on the water surface, and hence, contact mosquito larvae that feed below the surface, mainly at the tip of the siphon, result in their death. Further conidia enter through the spiracles, get germinated, invade the walls of the tracheae, and subsequently thought to release a toxin that kills the adults (Clark *et al.* 1968). Subsequent studies about the toxins of this genus confirmed that it contains the toxins as Beauvericin, Bassianin, Bassianolide, Beauverolides, and Tenellin from *B. bassiana* (Strasser *et al.* 2000). Hart and MacLeod (1955), who recorded the germination of *Beauveria* conidia described the requirement as RH above 94% for the growth of this fungus. However, infection does not appear to be dependent on temperature (Ferron 1981).

Metarhizium anisopliae: According to Boucias and Pendland (1998), this fungus has a large host-range, including arachnids and 5 orders of insects. On terrestrial insects, the life cycle begins with a conidium attaching to the host cuticle, forming an appressorium, followed by a penetration peg to enter the cuticle. After entering the hemocoel, hyphae formed produce and release toxins, killing the host in 4–16 days.These toxins released are Destruxins, Swainsinone, and Cytochalasin C (Strasser *et al.* 2000). If the conditions are warm and moist, conidiophores will grow through the cuticle to cover the insect with conidia. At breeding sites if conidia are applied on water surface, larvae come in contact with conidia through perispiracular valves during their air intake. The fungus germinates and penetrates into the respiration siphon, blocking the breathing mechanism (Daoust *et al.* 1982, Lacey *et al.* 1988). Plugging of the spiracles usually leads to death before significant invasion of the hemocoel occurs, so hyphal body formation is minimal. The optimal growth temperature for most strains is 27–28°C and RH 92% (Ferron 1981). However, recent work with locusts using oil-based formulations of *Metarbizium flavoviride* suggested that good control can be achieved even at very low environmental humidity. This impliedly indicated that in a tropical climate with low humidity level this fungus may prove as potent BCA against range of livestock pest.

Bacteria: Sampson and Gooday (1998) studied the involvement of chitinases of *Bacillus thuringiensis* in the pathogenesis to insects. They opined that exochitinases secreted by the bacilli produce chitinolytic action against larvae of *Culicoides nubeculosus*. Similarly, endogenous chitinases weaken the peritrophic membrane of insects, allowing the easy access of the bacterial toxins to gut epithelia. This indicated 2- fold *modus operandi* of the bacillus, in that it exerts on external chitin coverage as well as on internal epithelium of gut.

In addition to BCAs, following cultural/ managemental practices can form a part of IPM:

1. Hygiene/sanitation can be done by frequent manure removal in the shed for control of house flies and stable flies (Pickens *et al.* 1967).
2. Use of mineral fertilizer to change grassland biotypes (Dylko 1979), which helps in reducing the breeding sites of many fly species.
3. Forecasting of density and time of peak fly population are important steps for undertaking the control measures, hence shall be given due consideration.
4. Defining the feeding and biting sites, biting times and resting sites of the locally prevalent species and accordingly application of biopesticide, at the specific site and time only.
5. Larval habit management of *Culicoides* such as making water level fluctuation, adjusting edges slopes, drainage (Mullens 1991) helps in reducing the larval growth of *Culicoides.*
6. Use of baits, fogging/misting in barns (Harrington *et al.* 1997), which control house and stable fly populations.
7. Use of woodchips, ground corncobs or saw dust for bedding of calves (Schmidtmann 1991).
8. Animal husbandry is a key to prevent wool maggots. The operations such as lambing and shearing early in the season before onset of fly activity. Care in shearing the sheep will minimize wound sites. Prompt treatment or clipping of soiled fleece (Anonymous 1994).
9. Cleaning of calf pens on weekly basis significantly suppresses the development of house and stable flies (Geden *et al.* 1992).
10. Solar powered electrocuting trap (Pickens and Mills 1993) kills large number of flies.
11. Monitoring: By using (a) sticky cards, used for monitoring of house fly abundance and distribution patterns (Hogsette *et al.* 1993), light traps etc. Monitoring system is essential to determine the EIL (economic injury level) and ETL (economic threshold level) data mandatory for formulating the IPM module against a particular pest. Monitoring system should be designed for a particular region because National standards acceptable for population are impractical and impossible to define such threshold should be developed on a local basis to consider the legal demographic, social, environmental and economic parameters, all taken together to define a tolerable level of fly activity (Anonymous 1994). (b) Thompson and Connor (2000) recommended the environmental information systems such as remote sensing and spatial information technologies for control of arthropod vectors. Baylis *et al.* (1998) and Baylis and Rawlings (1998) used climate data and satellite imagery model to know the abundance of *Culicoides*, in which they estimated NDVI (normalized difference vegetation index) measure of photosynthetic activity and land surface temperature (LST) a measure of temperature at earth surface. NDVI and LST as predictors help in population peaks of flies.

Recent work undertaken in the author's lab on unconventional but feasible IPM methods

1. *Net shed for animals as a physical barrier:* Fly proof shed was prepared for the animals which were entirely covered with fine nylon (40 mesh size), rodent proof net. The purpose of shed was to minimize the bites of *Culicoides* midges in addition to other nocturnal biting flies. The shed constructed was of the size 30×30 feet with roof height of 14 feet. The shed roof was fitted with one hurricane type of ventilator with throat size 24 inch diameter working on the natural wind energy without requiring supply of electricity. It functions for replacement of hot air, humidity, stale air, smoke and gas fumes with fresh ambient air. Animals were let loose for grazing during day and maintained at night in the shed with tightly closed gate. Animal waste such as urine was passed through outlet which was immediately covered with lid. Analysis of data generated so far indicated that provision of fly proof shed results in increased milk yield by reduction in body movements. Continuous observations confirmed that in the shed, animal conserves energy which is generally spent in wiping out the flies + psychological disturbances has been converted into milk yield. Thermal humidity index (THI) and air changes study showed that there was not any discomfort to the animals, which was observed throughout the year covering all the 3 seasons. Physiological and behavioral parameters were within physiological range indicating more comfort to the animals in the shed. Economics of the shed indicated it as cost effective method. It helps in minimizing the contact between biting flies and host. Calvete *et al.* (2010) attempted the physical barrier as net for protection from *C. imicloa*, however he expressed concern over reduced air flow. But, this problem can be effectively handled by using ventilator and increasing the roof height more than 12 ft.
2. *Use of bacterial, fungal and herbal bio-pesticides for IPM of* Culicoides *sp.:* Laboratory evaluation followed by field studies (spraying on drainage channels as breeding sites where larvae of *Culicoides* midges were abundant) on five bacterial spores in the lyophilized powder form namely *Bacillus thuriengiensis* var *israelensis*, *B. spharicus*, *B. cereus* (CWBI-B1082), *B. weihenstephanensis* WSBC, *B. weihenstephanensis* KBAB4 and three herbal

pesticides namely neem oil (*Azadirachta indica*), karanj oil (*Pongamia pinata*) and nilgiri oil (*Eucalyptus globulus*) and laboratory evaluation of 2 fungal candidates powder containing 10^8 conidia/g namely *Metarhizuim anisopliae* and *Beauveria bezziana* @ 5 g fungal powder + 5 ml milk in 1litre of water on field collected larvae of *Culicoides* sp proved effective against larvae of *Culicoides* sp and hence, can form an integral part of IPM against these flies. The above mentioned fungal and herbal BCAs when evaluated in lab also exerted encouraging activity against the eggs of *Rhipicephalus* (*Boophilus*) *microplus* ticks and prevented 100% hatchability. More particularly fungus *Metarhizium* and Karanj oil played excellent role against tick especially expressing ovicidal activity.

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