Appendix I: Computer Code for model 1

```
;;=================================
;;Agent description
;;
globals [life_scale total_runs sinceAddGMO sinceFumigate]  ;; global variables
breed [Mbugs Mbug]   ;; Male bugs
breed [Fbugs Fbug]   ;; Female bugs
breed [Gbugs Gbug]   ;; GMO bugs

turtles-own [age repro]  ;;repro is the number of times female has laid eggs


;;======================================================
;; Here's what to do when user clicks the Setup button
;;------------------------------------------------------
to setup
  clear-all
  ask patches [ set pcolor 125 ]  ; Set color of background

  ; Add initial population of mosquitos female and male
  ; Add initial population of GMO mosquitos male
  setup-Mbugs    ; Create and scatter male mosquitos
  setup-Fbugs    ; Create and scatter female mosquitos
  setup-GBug     ; Create and scatter GMO mosquitos

  set life_scale 1.  ; scale for lifespan, used for environment capacity
  set total_runs 0   ; count how many times we started the program

  reset-ticks
end
;;======================================================


;;======================================================
;; Here's what to do when user clicks the Go button
;;-----------------------------------------------------
to go

 ;; Stop if all mosquitos are dead, reload mosquitos
 ;; and start simulation again.  Do this for up to
 ;; 20 times
 if count turtles = 0  ; No mosquitos left alive
 [
   if PourGMO = true or doFumigate = true [stop]
   set total_runs total_runs + 1
   if total_runs > 20 [ stop ]
   setup-Mbugs
   setup-Fbugs
   setup-GBug
   set life_scale 1.
 ]


 ;; Include maximum environment population capacity
```

```
;; If there are more than 1000 mosquitos make the
;; life span shorter in proportion to the exess population
;; so they die faster because of the overpopulation.
set life_scale 1000 / (count turtles)
if life_scale > 1 [ set life_scale 1.]

 bugsfly          ; Make mosquitos move one step
 make-more-bugs    ; Reproduce mosquitos

;; If the toggle to add GMO's every SBGMO steps is on, check
;; steps since last addition of GMO's and if needed call addGMO
if PourGMO = true
[
  set sinceAddGMO sinceAddGMO + 1
  if sinceAddGMO > SBGMO
  [
    addGMO
    set sinceAddGMO 0
  ]
]

;; If the toggle to fumigate every SBF steps is on, check
;; steps since last fumigation and if needed call fumigate routine
if doFumigate = true
[
  set sinceFumigate sinceFumigate + 1
  if sinceFumigate > SBF
  [
    fumigate
    set sinceFumigate 0
  ]
]
 tick
end
;;=====================================================
;;

;;=====================================================
;;
;; Here's what to do when user clicks the 'add GMO' button
;;-----------------------------------------------------
to addGMO
 create-Gbugs GMOBugs
 ask GBugs
 [
  setxy random-xcor random-ycor
  set age random 10
  set repro random 0
  set shape "butterfly"
  set color blue
  set size 3
 ]
end
;;=====================================================
;;

;;=====================================================
;;
```

```
;; Here's what to do when user clicks the 'fumigate' button
;;-----------------------------------------------------
to Fumigate
  ask Mbugs
  [ if random 100 < effectiveness [ die ] ]
  ask Fbugs
  [ if random 100 < effectiveness [ die ] ]
  ask Gbugs
  [ if random 100 < effectiveness [ die ] ]
end
;;=====================================================

;;=======================================
;;Procedures
;;=======================================

;;Procedure to place initial Male bugs
to setup-Mbugs
  create-Mbugs MaleBugs
  ask MBugs
  [
    setxy random-xcor random-ycor
    set age random MaleAge
    set repro random 2
    set shape "butterfly"
    set color green
    set size 3
  ]
end


;;Procedure to place initial Female bugs
to setup-Fbugs
  create-Fbugs FemaleBugs
  ask FBugs
  [
    setxy random-xcor random-ycor
    set age random FemaleAge
    set repro random 5
    set shape "butterfly"
    set color yellow
    set size 3
  ]
end

;;Procedure to place initial GMO bugs
to setup-Gbug
  create-Gbugs GMOBugs
  ask GBugs
  [
    setxy random-xcor random-ycor
    set age random Age
    set age 0
    set repro random 0
```

```
    set shape "butterfly"
    set color blue
    set size 3
  ]
end

;;Mosquitoes fly and die if old
to bugsfly
  ask Mbugs ;; Male bugs move and die if old
  [
    set age age + 1
    if age > (MaleAge - 5 + random 10) * life_scale
    [
      die
    ]
    set heading random 360
    forward random 5
  ]

  ask Fbugs ;; Female bugs move and die if old
  [
    set age age + 1
    if age > (FemaleAge - 5 + random 10) * life_scale
    [
      die
    ]
    set heading random 360
    forward random 5
  ]

  ask Gbugs ;; GMO bugs move and die if old
  [
    set age age + 1
    if age > (MaleAge - 5 + random 10) * life_scale
    [
      die
    ]
    set heading random 360
    forward random 5
  ]
end

;; Where female make more bugs
to make-more-bugs
  ask Fbugs
  [
    if age > 28 and repro < 3 and count Mbugs-here > 0
      [
        if ( random ( count Gbugs-here + count Mbugs-here ) + 1 ) > count Gbugs-here
          [
            if count Mbugs-here > random 2
            [
              set repro repro + 1
              hatch-Mbugs random Hatchlings
```

```
          [
            set age 0
            set shape "butterfly"
            set size 2
            set repro 0
            set color green
            set heading random 360
            forward random 100
          ]
          hatch-Fbugs random Hatchlings
          [
            set age 0
            set shape "butterfly"
            set size 3
            set repro 0
            set color yellow
            set heading random 360
            forward random 100
          ]
        ]
      ]
    ]
  ]
 ]
end
```

Appendix II: Computer Code for model 2

```
;;Program 101
;; Program about how GMO mosquitos affect natural population
;; agents- Natural-Male, Natural-Female, GMO-Male
;; all agents age
;; N-male + N-female = increase in population
;; GMO-male + N-female = decrease in population
;;female Live 2-3 weeks
;; female breeds 5 times
;;males breed once then die?
;;====================================
;;
;;Agent descriptiona
;;
breed [Mbugs Mbug]
breed [Fbugs Fbug]
breed [Gbugs Gbug]
breed [Persons Person]
breed [bats bat]
turtles-own [age repro bites sick? sickdays immune?]  ;;repro is the number of times female has
laid eggs


;;-----------------------------------------------------
;; Here's what to do when user clicks the Setup button
;;-----------------------------------------------------
```

```
to setup
  clear-all
  setup-Mbugs
  setup-Fbugs
  setup-GBug
  setup-Persons
  setup-bats


  ; Add initial population of mosquitos female and male
  ; Add initial population of GMO mosquitos male
  reset-ticks
end
;;====================================


;;====================================
;;Go section


to go

bugsfly
make_or_take_bats
make-more-bugs
make-Persons-Move
make-eat-Persons-Sick
make-bats-move
make-bats-eat-bugs
cull_bugs

tick

end


;;====================================


;; button to add GMO bugs
to addGMO
  create-Gbugs GMOBugs
  ask GBugs
  [
```

```
      setxy random-xcor random-ycor
      set age 1
      set repro random 0
      set shape "butterfly"
      set color blue
      set size 2
  ]
end


;;=====================================
;;Procedure
;;=====================================

;;Procedure to place initial Male bugs
to setup-Mbugs
  create-Mbugs MaleBugs
  ask MBugs
  [
    setxy random-xcor random-ycor
    set age random MaleAge
    set repro random 2
    set shape "butterfly"
    set color green
    set size 2
  ]
end



;;Procedure to place initial Female bugs
to setup-Fbugs
  create-Fbugs FemaleBugs
  ask FBugs
  [
  setxy random-xcor random-ycor
  set age random FemaleAge
  set repro random 4
  set shape "butterfly"
  set color pink
  set size 3
  set sick? false
  set bites random 4
  ]
end

;;Procedure to place initial GMO bugs
```

```
to setup-Gbug
  create-Gbugs GMOBugs
  ask GBugs
  [
  setxy random-xcor random-ycor
  set age random Age
  set repro random 2
  set shape "butterfly"
  set color blue
  set size 3
  ]
end


;;Procedure to add sick bugs
to addSickBugs
  ask FBugs
  [
  if random 100 < SickBugs
  [
  set color red
  set size 3
  set sick? true
  set sickdays 0
  ]
  ]
end


;;Place people
to setup-Persons
create-Persons Numpeople
  ask Persons
  [
   set color yellow
   set shape "face happy"
   set size 3
   setxy random-xcor random-ycor
   set age random 60
   set sick? false
   set immune? false
   set sickdays 0

  ]
end
```

```
to setup-bats
  create-bats BatCount
  ask bats
  [
    set shape "hawk"
    set size 4
    set color orange
    setxy random-xcor random-ycor
    set sick? false
  ]
end

;;_____
;; People move age and die

to make-Persons-Move
  ask Persons
    [
      set age age + 1
      if age > (5000 + random 500)
      [
        die
      ]
      if sick? = true
      [
        set sickdays sickdays + 1
        if sickdays > 27
        [
        set sick? false
        set color yellow
        set shape "face happy"
        set immune? true
        ]
      ]
      set heading random 360
      forward random 5
    ]
end

to make-bats-move
  ask bats
  [
    set heading random 360
    forward random 15
```

```
  ]
end


;;_____
;;Fly and Die
;;Mosquitoes fly and die if old
to bugsfly
  ask Mbugs ;; Male bugs move and die if old
  [
  set age age + 1
  if age > (MaleAge - 1 + random 3)
  [
    die
  ]
  set heading random 360
  forward random 5
  ]

  ask Fbugs ;; Female bugs move and die if old
  [
   set age age + 1
   if age > (FemaleAge - 2 + random 5)
  [
    die
  ]
    set heading random 360
    forward random 5
  ]

  ask Gbugs ;; GMO bugs move and die if old
  [
  set age age + 1
   if age > (MaleAge - 1 + random 3)
  [
    die
  ]
  set heading random 360
  forward random 5
  ]
end

;;_____
;; Where female make more bugs
to make-more-bugs
ask Fbugs
```

```
[
  if repro < 3
  [
    if count Mbugs-here > 0
    [
      if ( random ( count Gbugs-here + count Mbugs-here ) + 1 ) > count Gbugs-here
      [
        set repro repro + 1
        ifelse sick? = true
        [
        hatch-Mbugs random Hatchlings
        [
          set age 1
          set shape "butterfly"
          set size 2
          set repro 0
          set sick? true
          set color red
          set heading random 360
          forward random 25
        ]
        hatch-Fbugs random Hatchlings
        [
          set age 1
          set shape "butterfly"
          set size 3
          set repro 0
          set sick? true
          set color red
          set heading random 360
          forward random 25
        ]
        ]
        [
          hatch-Mbugs random Hatchlings
          [
            set age 1
            set shape "butterfly"
            set size 2
            set repro 0
            set sick? false
            set color green
            set heading random 360
            forward random 25
          ]
```

```
     hatch-Fbugs random Hatchlings
     [
       set age 1
       set shape "butterfly"
       set size 3
       set repro 0
       set sick? false
       set color pink
       set heading random 360
       forward random 25
     ]
    ]
    ask one-of Mbugs-here
    [
      die
    ]
   ]
  ]
 ]
]

end

;;_____
;; Persons get sick
to make-Persons-Sick

ask Fbugs
[
if sick? = true
   [
      if count Persons-here > 0
        [
          if random 100 > 50
            [
              ask Persons-here
               [
                 set color red
                 set shape "face sad"
                 set sick? true
               ]
            ]
        ]
   ]
]
```

```
end
;;===========================================
;; Bugs eat and transmit
to make-eat-Persons-Sick

ask Fbugs
[
if bites < 3
    [
       if count Persons-here > 0
             [
                set bites bites + 1
                if sick? = true
                [
                ask one-of Persons-here
                  [
                    if sick? = false and immune? = false
                    [
                    set color red
                    set shape "face sad"
                    set sick? true
                    ]
                  ]
                ]
             ]
    ]
]
end
```

```
;;===========================================
;; Control excessive bats

to cull_Bugs
  ask Mbugs
  [
  if count Mbugs > 5000
  [
    pd repeat ( count Mbugs - 5000 )
    [
      ask one-of Mbugs
```

```
      [
        die
      ]
    ]
  ]
  ]
  ask Fbugs
  [
  if count Fbugs > 5000
  [
    pd repeat ( count Fbugs - 5000)
    [
      ask one-of Fbugs
      [
        die
      ]
    ]
  ]
  ]
]


end

;;_____
;;make-bats
to make_or_take_bats
  if-else ( (count Gbugs + count Mbugs + count Fbugs) / ( 1 + count bats )) > 5
  [
    create-bats round  (((count Gbugs + count Mbugs + count Fbugs) / ( 1 + count bats )) * 5 )
    ask bats
    [
      set shape "hawk"
      set size 3
      set color orange
      setxy random-xcor random-ycor
      set sick? false
    ]
  ]
;;if too many, start to take away bats
  [
    ask bats
    [
      if random 100 < 2
      [
        die
```

```
      ]
    ]
   ]
 end


  ;;=======================================
  to make-bats-eat-bugs
  ask bats
  [
    if (count Mbugs-here + count Gbugs-here + count Fbugs-here) > 0
    [
      ask Mbugs in-radius 3
      [
       if random 100 < 75  ;; how effective bats are in eating bugs
       [
         die
       ]
      ]
      ask Gbugs in-radius 3
      [
       if random 100 < 75
       [
         die
       ]
      ]
      ask Fbugs in-radius 3
      [
       if random 100 < 75
       [
         die
       ]
      ]
    ]
  ]
 end


to make-more-persons
  ask persons
  [
    if age > 15
    [
      if repro < 3
    [
      if count persons-here > 0
      [
```

```
    if ( random ( count persons-here + count persons-here ) + 1 ) > count Gbugs-here
    [
      hatch-persons random Hatchlings
      [
        set age 1
        set shape "face happy"
        set size 1.5
        set repro 0
        set color blue
        set heading random 360
        forward random 25
      ]
    ]
      ]
    ]
    ]
 ]
end


-------------

4)incorporating review suggestions i.e., introduction of confined spaces and targeted releases ??
```

Appendix III: Computer Code for model 3

```
;;========================================
;;Agent descriptiona
;;
;; simply start with part of population sick and part well and try and infect the well ones
;; next can add contagiousness factor less than 1
;; then can add lifespan and reproduction

;; next- make baby mosquitoes sick or healty based on parent
;; then we can add GMO and kill the babies of the gmo at day 1

breed [Bats Bat] ;; define agentset by giving name of plural set and singular agent (bat)
breed [mosquitoes mosquito]

turtles-own [sick? age sterile daysSick gmo? female?]

;;===============================================================
;;
============================
;;globals, unneccesary

globals
[ lifespan ]   ;;lifespan of sick turlte

;;===============================================================
;;
============================
;;setup
to setup
        clear-all
        setup-patches
        setup-mosquitoes
        setup-bats
        reset-ticks
end

to setup-patches
  ask patches [ set pcolor green ]
end

to setup-constants
  set lifespan 200  ;; how can we make the lifespan a variable
```

```
end

to setup-mosquitoes
  create-mosquitoes number
   [ setxy random-xcor random-ycor
          set color blue
          set shape "bug"
          set sick? false
          set gmo? false
          set female? false
          set age random 200] ; start mosquitoes with random age

  ask n-of number-infected mosquitoes
          [ get-sick ]
          ask n-of number-gmo mosquitoes
          [ get-gmo? ]
          ask n-of number-female mosquitoes
          [ get-female
          set size 2.5 ]
end


to setup-bats
  create-bats BatCount
  ask bats
  [
          set shape "star"
          set size 2
          set color orange
          setxy random-xcor random-ycor
          set sick? false
          set gmo? false
          set female? false ;; bats are treated as male, not GMO, not sick
  ]
end

;;===============================================================
;;=======
;;to-do

to GO!
  if count mosquitoes > 499
  [ show "STOP!!!"
          stop
  ]
```

```
  if count mosquitoes < 1
[ show "STOP 0!!!"
        stop
]

if count mosquitoes > 0
[if count mosquitoes < 500
[ask mosquitoes [
move
 if sick? [ infect ]
        mate
        increase-age ]
tick
make-bats-move]
]

end

to move
  right random 360
        forward 1
 ;;  if sick? [ infect ]
 ;;  mate
 ;;  increase-age

end

;;========================================================================
================

to get-sick ;; turtle procedure
  set sick? true
  set color red
 ;; show  "start SICK***"
end

to get-gmo? ;;gmo
  set gmo? true
  set female? false
  set color 0
end

to get-female ;; gender
  set female? true
```

```
  set size 2.5
;;  show "make female :)"
end



to make-bats-move
  ask bats
  [
        set heading random 360
        forward random 15
  ]
  bats-eat-bugs
end



;; If a turtle is sick, it infects other mosquitoes on the same patch.
 ;;Immune mosquitoes don't get sick.

to infect ;; turtle procedure
  show  "INFECTING"
  ask other mosquitoes-here with [ not sick? ]
        [  set sick? true
  set color red
  set size 2
  show  "GET SICK***"
        ]



end

to increase-age
 ;; ask mosquitoes
  set age age + 1
  show "aging"
;;  if  age > 200 [ die ]

        if sick?
        [
        if age > 100 [ die ]
        ]
        if not sick?
        [
        if age > 200 [ die ]
        ]
        end
```

```
to bats-eat-bugs
  ask bats
  [
        ask mosquitoes in-radius 2
        [
        if random 100 < 20
        [
        die
        ]
        ]
;;  show "eating"
  ]
end


;;=====================================================================
;;
=======
;;babies!

 to mate
  ;; print  "MATE"
  if age > 2   [ ask other mosquitoes-here with [ not female?]
 [
   ;;if [ not gmo? ]
        reproduce


        ]
 ]
 end




to reproduce
  ask other mosquitoes-here with [ female? ]
        [if random 100 < 30
        [hatch 2
        set age 1
        set shape "butterfly"
        ifelse random 100 < 50 [ set female? false
        set size 1
        ]
        [set female? true
        set size 2]
        ]
```

```
        ]
end
```