2.6.2 Summary Quiz: Paradox of the Pesticides

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In this quiz, you'll explore another predator-prey situation and the impact of human intervention, using the Lotka-Volterra model.

Pesticides are used to kill off a pest that is a nuisance to crops. However, sometimes the use of the pesticide can paradoxically increase the population of the pests. Let's see how this can happen.

Consider an Australian cicada species which causes damage to sugarcane fields and its predator, a cicada-killer wasp. (See the Cicada entry on Wikipedia and Species of economic importance by L.W. Popple, University of Queensland, Australia.)

We'll model their relationship with the following predator-prey system where C is the size of the prey cicada population and W is the size of the predator wasp population and a, b, c and d are parameters:

$$\frac{dC}{dt} = aC - bCW$$

$$\frac{dW}{dt} = -cW + dCW.$$

Question 1

5/5 points (graded)

Suppose we spray a pesticide on the sugarcane fields that affects insects at a rate proportional to the amount of insects, where q is the constant of proportionality. Now, this pesticide may affect both the predator and prey insects, or it may target one and not the other. Let's consider these different situations.

Match each situation model below with the most appropriate description.

A.

$$\frac{dC}{dt} =(a - q)C - bCW$$

$$\frac{dW}{dt} = -(c + q)W + dCW$$

- [ ] Pesticides kill wasps but not cicadas.
- [x] Pesticides kill both wasps and cicadas. ✔
- [ ] Neither wasps nor cicadas are affected by pesticides.
- [ ] The wasps are unaffected by pesticides, but the cicadas are.
- [ ] Pesticides do not kill cicadas but they weaken them making it easier for the wasps to eat more of them.

B.

$$\frac{dC}{dt} = (a-q)C - bCW$$
$$\frac{dW}{dt} = -cW + dCW$$

- [ ] Pesticides kill wasps but not cicadas.
- [ ] Pesticides kill both wasps and cicadas.
- [ ] Neither wasps nor cicadas are affected by pesticides.
- [x] The wasps are unaffected by pesticides, but the cicadas are. ✔
- [ ] Pesticides do not kill cicadas but they weaken them making it easier for the wasps to eat more of them.

C.

$$\frac{dC}{dt} = aC - (b+q)CW$$
$$\frac{dW}{dt} = -cW + (q+d)CW$$

- [ ] Pesticides kill wasps but not cicadas.

- Pesticides kill both wasps and cicadas.
- Neither wasps nor cicadas are affected by pesticides.
- The wasps are unaffected by pesticides, but the cicadas are.
- Pesticides do not kill cicadas but they weaken them making it easier for the wasps to eat more of them. ✔

D.

$$\frac{dC}{dt} = aC - bCW$$
$$\frac{dW}{dt} = -(c+q)W + dCW$$

- Pesticides kill wasps but not cicadas. ✔
- Pesticides kill both wasps and cicadas.
- Neither wasps nor cicadas are affected by pesticides.
- The wasps are unaffected by pesticides, but the cicadas are.
- Pesticides do not kill cicadas but they weaken them making it easier for the wasps to eat more of them.

E.

$$\frac{dC}{dt} = aC - bCW$$
$$\frac{dW}{dt} = -cW + dCW$$

- Pesticides kill wasps but not cicadas.
- Pesticides kill both wasps and cicadas.

- (selected) Neither wasps nor cicadas are affected by pesticides. ✔
- The wasps are unaffected by pesticides, but the cicadas are.
- Pesticides do not kill cicadas but they weaken them making it easier for the wasps to eat more of them.

Explanation
For (a), if pesticides kill both wasps and cicadas at a rate proportional to population, this affects both populations. The rate out for cicadas now includes $-qC$ and the rate out for wasps now includes $-qW$.

$$\frac{dC}{dt} = aC - bCW - qC = (a-q)C - bCW$$
$$\frac{dW}{dt} = -cW + dCW - qW = -(c+q)W + dCW$$

For (b), the wasps are unaffected by pesticides, but the cicadas are, meaning the wasp equation is unchanged but $\frac{dC}{dt} = (a-q)C - bCW$.
For (d), it's the other way around, meaning the cicada equation is unchanged but $\frac{dW}{dt} = -(c+q)W + dCW$.
For (e), neither are affected so the system is unchanged.
For (c), the rate out of cicadas is not directly proportional to the amount of cicadas but relies instead on the interaction of wasps and cicadas, hence the interaction term CW is affected for both cicadas and wasps.

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Answers are displayed within the problem

Question 2

1/1 point (graded)
The system

$$\frac{dC}{dt} = aC - bCW$$

$$\frac{dW}{dt} = -cW + dCW.$$

has $(0,0)$ as one equilibrium point. Where is the other equilibrium of the predator-prey system before the application of the pesticides?

- $(c/d, 0)$
- $(0, (a/b)$
- $(c/d, a/b)$ ✔
- $(a/b, c/d)$
- None of the above.

Explanation

$(c/d, a/b)$. This comes from looking at intersection of nullclines. To find the equilibrium point, we want to solve for the values of C and W such that $\frac{dC}{dt} = 0 = \frac{dW}{dt}$. Note that we could graphically see the equilibrium position by performing a phase plane analyses and looking for the intersection point of nullclines in wasp and cicada populations. Solving the above equations, we have:

$$aC - bCW = 0$$
$$a - bCW = 0$$
$$W = \frac{a}{b}$$

$$-cW + dCW = 0$$
$$-c + dC = 0$$
$$C = \frac{c}{d}$$

Thus, the equilibrium values are $(C, W) \in \{(0, 0), (c/d, a/b)\}$.

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Question 3

1/1 point (graded)

Where is the equilibrium of the predator-prey system after the application of the pesticides?

- The equilibrium is not affected by the application of pesticides.
- It changes to $((c + q)/d, (a + q)/b)$

- It changes to $((c-q)/d,(a-q)/b)$
- It changes to $((c-q)/d,(a+q)/b)$
- It changes to $((c+q)/d,(a-q)/b)$ ✔
- None of the above.

Explanation
$((c+q)/d,(a-q)/b)$. This comes from looking at intersection of nullclines. As with the sardine-marlin problem, rather than solve the new equations for the static solution, we can substitute the new equation parameters into our formulas for equilibrium populations from the previous question. When we introduce the pesticide, we see that $a \to a-q$ and $c \to c+q$. Thus, the equilibrium values for this new system of equations are $(C,W) \in \{(0,0),(\frac{c+q}{d},\frac{a-q}{b})\}$.

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Question 4

1/1 point (graded)
Which of the following best describes the change in the average population of cicadas and wasps after the application of pesticides? Choose the best answer.

- The average value of both populations decreases after the pesticide is applied, but it decreases more for the predator wasp.
- The average value of both populations decreases after the pesticide is applied, but it decreases more for the prey cicadas.
- The average value of the prey cicadas increases and the average value of the predator wasps decrease. ✔
- The average value of the predator wasps increases while the average value of the prey cicadas decrease.
- The average value of both populations increases after the pesticide is applied, but it increases more for the prey cicadas.

Explanation

The equilibrium values for this new system of equations are $(C, W) \in \{(0,0), (\frac{c+q}{d}, \frac{a-q}{b})\}$.
Remember that, since the cicada-wasp equations are completely parallel to the sardine-marlin equations, the non-equilibrium population trajectories here will also be closed cycles with average values equal to the equilibrium values: $\overline{C} = \frac{c+q}{d}$ and $\overline{W} = \frac{a-q}{b}$.
We see that if q is positive (pesticides are applied), then the average number of cicadas increases while the average number of wasps decreases. The next question asks for a biological interpretation of this result.

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Question 5

1/1 point (graded)
Why is this called sometimes “the paradox of the pesticides”? How might you explain what’s happening biologically?

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Since the pesticide kills more wasps it results in increase
in cicadas.
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Thank you for your response.

Explanation

The paradox we face here is similar to the one with the marlin and sardines. We introduce pesticide, which universally decreases all insect populations at a given rate. However, somewhat counterintuitively, this leads to a larger average value for the cicadas. Thinking in terms of cycles, this means the average population of cicadas over one full cycle is higher with the pesticide than without the pesticide.
Physically, we can deduce that pesticide decreases the wasp population, and this in turn decreases the number of cicadas being killed by wasps. Thus, while the pesticide acts directly to decrease cicada population, it indirectly increases cicada population by decreasing the number of predators killing cicadas. The indirect effect is stronger than the direct effect here, causing the pesticide to increase the cicada population overall.

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