U.M.S.S. NAMUGONGO

PERSEVERANCE & SUCCESS

UGANDA MARTYRS S.S NAMUGONGO

PROPOSED RESPONSES TO THE

GRAND ANNUAL UMSSN

A'LEVEL BIOLOGY SEMINAR QUESTIONS 2026



ASSESSMENT OBJECTIVE 1: CELLULAR ORGANISATION, RESPIRATION, AND MOLECULAR ANALYSIS

Item 1

a) RNA polymerase activity, blaZ transcription and antibiotic inhibition zone

RNA polymerase activity was higher in resistant bacteria than in antibiotic-sensitive bacteria; **AI**, due to the plasmid containing the regulatory gene *blaI*, whose product BlaI promoted high transcription of the *blaZ* gene; **Ae**, the high RNA polymerase activity increased transcription of *blaZ*, leading to increased production of an mRNA in the nucleus that was taken to the ribosomes in the cytoplasm for translation. This was translated into a sequence of amino acids and, upon folding, formed a functional β-lactamase protein. This enzyme breaks down the β-lactam ring in penicillin-type antibiotics, resulting in a smaller antibiotic inhibition zone diameter in resistant bacteria than in sensitive bacteria. This enzymatic breakdown reduced the effective concentration of the antibiotic at the bacterial cell wall, allowing resistant bacteria to survive, multiply, and produce other virulence factors, which delayed wound healing in infected patients; **Ap**

ATP synthesis rate, bacterial multiplication and bacterial survival

ATP synthesis rate was higher in resistant bacteria than in antibiotic-sensitive bacteria; **AI**, due to the glucose-rich wound exudate; **Ae**, the exudate provided abundant substrates for aerobic respiration where glucose was broken down, producing direct ATP molecules and the reduced NAD and FAD that released hydrogen atoms in the mesosome and more ATP produced during oxidative phosphorylation. The high amount of ATP provided the energy required for DNA replication, protein synthesis, and cell division, leading to a higher mitotic index of the resistant bacterial cells compared to the antibiotic-sensitive bacteria. This rapid multiplication increased the population of resistant bacteria, hence a higher percentage of bacterial survival in resistant bacteria compared to sensitive bacteria despite antibiotic treatment, overwhelming the host immune defenses and delaying wound healing; **Ap**

b) Switching patients to an alternative antibiotic

It is effective; **EI**, this kills the resistant bacteria reducing tissue damage and allow wound healing to proceed; however, the resistant bacteria carry a plasmid that can acquire or transfer additional resistance genes, so they may quickly develop resistance to it, allowing

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them to survive and multiply; **Ee**, therefore, it should be maintained but guided by laboratory sensitivity testing and antisense drugs; **Ep**

Strengthening handwashing practices among staff

It is effective; **EI**, this reduces the transmission of resistant bacteria between patients, prevents contamination of wound-care materials, limiting the spread of resistant strains from infected to non-infected patients in the same ward; however, hand washing without disinfectants leaves some strains and also inconsistent handwashing among the patients maintains the transmission of resistant bacteria; **Ee**, therefore, this should be maintained but combined with disinfectants, provision of adequate handwashing facilities and ensure handwashing in both the staff and patients; **Ep**

Introducing bacteriophage therapy

It is effective; **EI**, bacteriophages specifically infect and kill bacteria, including antibiotic-resistant strains, offering an alternative treatment when antibiotics are ineffective due to β-lactamase production; however, bacteriophages are highly specific to particular bacterial strains, so they may allow proliferation of the other *Staphylococcus aureus* strains present in the ward; **Ee**, therefore, bacteriophage therapy should be maintained but with careful selection of phages matched to the infecting strain and used alongside other treatments; **Ep**

Item 2

a) Carboxyhaemoglobin concentration, oxygen transport and lactic acid concentration

Carboxyhaemoglobin concentration was higher in workers than in normal individuals; **AI**, due to inhalation of carbon monoxide produced by the old fluid bed dryers during the drying of wet granules and powders in the poorly ventilated production wing; **Ae**, carbon monoxide entered the workers' blood and combined with haemoglobin, forming carboxyhaemoglobin, this reduced the amount of haemoglobin available to carry oxygen, so less oxygen was delivered to the tissues. The reduced oxygen supply forced cells to rely more on anaerobic respiration, increasing lactic acid production, which resulted in a higher lactic acid concentration in workers compared to normal individuals, hence the unusual fatigue during physical tasks; **Ap**

Cytochrome c oxidase activity, mitochondrial respiration and lactic acid concentration

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Cytochrome c oxidase activity was lower in workers than in normal individuals; **AI**, due to carbon monoxide interfering with mitochondrial respiration by inhibiting cytochrome c oxidase; **Ae**, cytochrome c oxidase is the final enzyme in the electron transport chain, so its inhibition slowed down the transfer of electrons to oxygen, reducing oxidative phosphorylation and ATP production in the mitochondria. With less ATP produced aerobically, cells increasingly relied on anaerobic respiration to meet their energy demands, producing more lactic acid as a by-product, which resulted in a higher lactic acid concentration in workers compared to normal individuals, leading to unusual fatigue during physical tasks; **Ap**

The reduction in ATP production reduced the amount of energy available for mitosis, hence a lower mitotic index of skin epithelial cells in the workers compared to the normal individuals. Cell division is an energy-demanding process that requires ATP for DNA replication, spindle formation, and cytokinesis; with less ATP available, fewer skin epithelial cells were able to complete mitosis, so the rate of cell division was reduced, which resulted in a lower tissue formation rate in workers compared to normal individuals. This limited the number of new cells available to replace damaged tissue during wound repair, leading to slow healing of minor skin wounds; **Ap**

b) Improving ventilation

It is effective; **EI**, this allows exchange of air with the surrounding environment, which removes carbon monoxide from the air before it can be inhaled, reducing the formation of carboxyhaemoglobin and preventing the inhibition of cytochrome c oxidase, thereby restoring oxygen transport and mitochondrial ATP production; however, poorly designed ventilation systems may create uneven airflow that leaves some areas still contaminated; **Ee**, therefore, improving ventilation should be implemented alongside carbon monoxide detectors for regular monitoring of air quality and carbon monoxide levels to ensure the system is working effectively; **Ep**

Planting trees around the wing

It is effective; **EI**, this improves air quality in the surrounding environment since trees absorb carbon dioxide that may be formed after air oxidation of the carbon monoxide, improving the aesthetic environment for workers; however, trees take many years to mature, and their overgrowth may disrupt the wing ventilation; **Ee**, therefore, planting trees should be implemented but with proper planning of distance from the building and practices like pruning to prevent obstructing ventilation; **Ep**

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Replacing the faulty equipment

It is **effective**; **EI**, it eliminates the source of carbon monoxide production, preventing the formation of carboxyhaemoglobin and protecting mitochondrial respiration, thereby restoring oxygen transport, ATP production, and normal cell division for wound healing; however, replacing equipment without maintenance allows continuous carbon monoxide; **Ee**, therefore, replacing the faulty equipment should be implemented but with regular maintenance schedules to ensure worker safety; **Ep**

Item 3

a) Mean number of cristae per mitochondrion, aerobic ATP production and running time

Mean number of cristae per mitochondrion was lower in Amina than in the healthy individual; **AI**, due to an inherited mutation in the *OPA1* gene; **Ae**, this gene codes for a protein in the inner mitochondrial membrane responsible for folding the membrane into cristae; fewer cristae were produced, which reduced the surface area of the inner mitochondrial membrane available for the electron transport chain and ATP synthase, reducing the rate of oxidative phosphorylation, hence a lower ATP production during exercise in Amina than in the healthy individual. With less ATP available for muscle contraction, Amina's muscles could not sustain rapid, powerful contractions, so her 100 m running time was higher than that of the healthy individual; **Ap**

Aerobic ATP production, anaerobic respiration and blood lactate concentration

Aerobic ATP production during exercise was lower in Amina than in the healthy individual; **AI**, due to the inhibitory effect of abnormally high malonate levels on succinate dehydrogenase in the Krebs cycle; **Ae**, malonate inhibits succinate dehydrogenase, so the Krebs cycle is slowed down, reducing the supply of reduced coenzymes (NADH and $FADH_2$) to the electron transport chain, combined with the reduced cristae surface area, this further lowered aerobic ATP production to meet the energy demands of sprinting, Amina's muscle cells relied more on anaerobic respiration, which produces ATP rapidly but also produces lactic acid hence a higher blood lactate concentration after sprinting in Amina compared to the healthy individual which needed more time for is complete conversion hence contributing to increased muscle fatigue and cramps; **Ap**

b) Controlled aerobic training

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It is effective; **EI**, regular moderate aerobic exercise stimulates mitochondrial biogenesis, increasing the number and size of mitochondria and the density of cristae in muscle cells, which raises the surface area for the electron transport chain and ATP synthase, improving aerobic ATP production and reducing reliance on anaerobic respiration; however, Amina's *OPA1* mutation limits cristae folding, so the increase in cristae density may be less and intensive sprint training five days a week may still cause fatigue and cramps if not carefully controlled; **Ee**, therefore, it should be implemented with gradual progression, adequate rest days and monitoring of lactate levels; **Ep**

Feeding on enough carbohydrates

It is effective; **EI**, carbohydrates are broken down to glucose, which is the main substrate for both aerobic and anaerobic respiration; adequate carbohydrate intake before training maintains blood glucose concentration, increases muscle glycogen stores and provides more substrate for ATP production; however, consumption of excess carbohydrates may increase the blood sugar levels and hence increased fat deposition; **Ee**, therefore, feeding on enough carbohydrates should be implemented, but they should be eaten in moderate amounts; **Ep**

Gene-based treatment

It is effective; **EI**, it corrects the mutated *OPA1* gene, restoring normal folding of the inner mitochondrial membrane into cristae, which would increase the surface area for the electron transport chain and ATP synthase, improving aerobic ATP production and reducing lactate accumulation; however, gene-based treatment is still largely experimental, may have off-target effects, and requires efficient delivery systems to reach the mitochondria in muscle cells; **Ee**, therefore, gene-based treatment should be maintained but requires further research, clinical trials and regulatory approval before routine use; **Ep**

Item 4

a) Membrane transport efficiency, nutrient uptake and bacterial survival

Membrane transport efficiency was lower in the affected batch than in the normal batch; **AI**, due to the contaminant, a phenolic disinfectant residue, damaged bacterial cell membranes; **Ae**, the disinfectant residues distorted the plasma membrane proteins, changing their 3-D structure by disrupting hydrophobic interactions, hydrogen bonds, ionic bonds and other membrane components, altering its fluidity and selective permeability, which reduced membrane integrity, reducing the uptake of nutrients such as glucose and amino acids and

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the excretion of waste products. This disrupted metabolism and reduced the ability of the bacteria to maintain homeostasis, so many cells died, which resulted in lower bacterial survival and protein production in the affected batch compared to the normal batch, leading to a reduction in recombinant protein production; **Ap**

ATP production, energy supply and bacterial survival

ATP production was lower in the affected batch than in the normal batch; **Al**, due to sodium azide, a respiratory poison; **Ae**, sodium azide non-competitively inhibited cytochrome c oxidase enzyme, interfering with transfer of electrons to oxygen; hydrogen atoms accumulate, ceasing aerobic respiration, hence lower ATP generated, which reduces active uptake of nutrients, activation of amino acids in protein synthesis, decreasing biosynthesis, which reduces survival of cells; resulting in lower percentage of bacterial cells and lower insulin production in affected batch compared to normal batch, leading to a reduction in recombinant protein production; **Ap**

Successful amplification of the target, bacterial survival and protein production

Successful amplification of the target was lower in the affected batch than normal batch; **Al**, due to repeated overheating during PCR that denatured some of the DNA polymerase enzymes; **Ae**, denaturation of DNA polymerase interfered with synthesis of new DNA strands from added primers, causing many DNA samples fail to amplify before gene cloning therefore fewer copies of target DNA were formed which reduced the number of mRNA formed after transcription in bacterial cells and very few polypeptides(enzymes) formed after translation in ribosomes; which resulted in a lower percentage of bacterial cells and lower recombinant protein production in the affected batch compared to the normal batch; **Ap**

b) Strengthen aseptic handling and contamination-control procedures

It is effective; **El**, it prevents the entry of contaminants such as phenolic disinfectant residues into the bacterial cultures, protecting bacterial cell membranes from damage, maintaining membrane transport efficiency and ensuring adequate nutrient uptake for bacterial survival and growth; however, aseptic procedures require regular training, strict supervision and adequate resources such as sterilising equipment; **Ee**, therefore, aseptic handling and contamination-control procedures should be implemented with regular staff training, routine monitoring of contamination levels; **Ep**

Monitor PCR temperature precisely using validated cycling conditions

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It is effective; **EI**, monitoring PCR temperature precisely using validated cycling conditions improves recombinant protein production since it prevents overheating of PCR tubes, protecting the DNA polymerase from heat damage and ensuring efficient amplification of the target gene; however, precise temperature monitoring requires calibrated thermocyclers, and equipment failure or power fluctuations may still cause temperature deviations; **Ee**, therefore, precise PCR temperature monitoring should be implemented with regular calibration, maintenance of thermocyclers and backup power supply, to ensure reliable amplification; **Ep**

Use of hydroxocobalamin (Vitamin B12a) to support energy production in affected cultures

It is effective; **EI**, hydroxocobalamin may support energy production in affected cultures since it can bind to the respiratory poisons, potentially reducing the inhibition of cytochrome oxidase and allowing some recovery of aerobic ATP production; however, hydroxocobalamin traces may induce allergic reactions in some people; **Ee**, therefore, hydroxocobalamin should be used in limited amounts and caution should be provided in case it is used; **Ep**

Item 5

a) Tumour suppressor protein concentration, cell cycle control and tumour diameter

Tumour suppressor protein concentration was lower in David than in the healthy person; **AI**, due to a mutation in the *TP53* gene; **Ae**, this gene normally produces a tumour suppressor protein that halts the cell cycle when DNA is damaged, the mutated *TP53* gene transcribed into a wrong mRNA and this translated into a non-functional tumour suppressor protein, so cells with damaged DNA were able to cross the cell cycle checkpoints moving from the S-phase to the G2 phase and hence these cells continued to divide without repair, accumulating further mutations and forming a growing mass in the colon; which resulted in a larger tumour diameter after 3 months in David compared to the healthy person, and the persistent abdominal pain and blood in his stool; **Ap**

RNA polymerase activity, c-Myc overexpression and tumour diameter

RNA polymerase activity was higher in David than in the healthy person; **AI**, due to abnormally high levels of c-Myc, a transcription factor that binds to DNA and increases RNA polymerase activity; **Ae**, the elevated c-Myc levels increased the transcription of genes producing mRNAs that translated into proteins such as cyclins and growth factors that promote cell division and growth. This accelerated the rate at which colon cells progressed

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through the cell cycle, so more cells divided and the tumour expanded rapidly, resulting in a larger tumour diameter after 3 months in David compared to the healthy person; **Ap**

Mitochondrial activity, energy supply and tumour diameter

Mitochondrial activity was higher in David than in the healthy person; **AI**, due to David's use of a dietary pill containing coenzyme Q10 (CoQ10) for the past two years, which he believed would boost his energy levels; **Ae**, CoQ10 is a component of the electron transport chain, so it increased mitochondrial ATP production. The increased ATP production increased the amount of energy available for mitosis, hence a higher mitotic index in David compared to the healthy person. Cell division is an energy-demanding process that requires ATP for DNA replication, spindle formation, and cytokinesis; therefore, the extra ATP provided the energy needed for the rapid cell division and protein synthesis occurring in the tumour cells, supporting their uncontrolled proliferation, which resulted in a larger tumour diameter after 3 months in David compared to the healthy person; **Ap**

b) Surgery

It is effective; **EI**, it physically removes the tumour mass from his colon, reducing the number of cancer cells and relieving symptoms such as blood in the stool and abdominal pain, and it can prevent the tumour from spreading to other parts of the body; however, there is a risk of complications such as infection, bleeding and damage to surrounding tissues, and it also leaves the metastatic cells in the blood and lymph; **Ee**, therefore, surgery should be implemented with taking antibiotics and iron supplements; **Ep**

Chemotherapy

It is effective; **EI**, the cytotoxic drugs kill rapidly dividing cancer cells, including those that may have spread beyond the colon, and it can shrink the tumour before surgery or eliminate remaining cancer cells after surgery; however, chemotherapy also affects normal rapidly dividing cells such as those in the bone marrow, hair follicles and gut lining, causing side effects such as anaemia, hair loss, nausea and increased risk of infection; **Ee**, therefore, chemotherapy should be implemented with bone marrow and stem cell transplant after treatment; **Ep**

Radiotherapy

It is effective; **EI**, the high-energy radiation damages the DNA of cancer cells, causing them to stop dividing and die, and it can be targeted precisely at the tumour site to shrink the tumour and reduce symptoms; however, radiotherapy can also damage nearby healthy

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tissues, causing side effects such as skin irritation, fatigue and damage to the colon; **Ee**, therefore, radiotherapy should be done with precise targeting, careful dose planning and monitoring of side effects; **Ep**

Gene therapy

It is effective; **EI**, gene therapy corrects the mutated *TP53* gene by introducing a functional copy of the gene into his colon cells, restoring the production of functional tumour suppressor protein that can halt the cell cycle when DNA is damaged and prevent uncontrolled cell division; however, it may have off-target effects, and some vectors like viruses may carry oncogenes and further escalate the challenge; **Ee**, therefore, it be maintained but proper excision of the oncogenes from the vectors; **Ep**

Item 6

a) Polymerase activity, protein synthesis and plasma albumin concentration

Polymerase activity was lower in affected children than in healthy children; **AI**, due to severe food shortages following prolonged flooding, where families relied only on available rice, which is predominantly carbohydrate and low in protein; **Ae**, the reduction in protein intake reduces the number of amino acids available for translation using the mRNA molecules formed after transcription; this in the end reduced the transcription rate. This therefore reduced the formation of proteins, for example, antibodies that are needed in providing immunity. This therefore reduced the affected children's immunity, leading to their presentation with recurrent infections; **Ap**

The reduced protein synthesis reduced the synthesis of plasma albumin by the liver, leading to a lower plasma albumin concentration in the affected children compared to the healthy children. Albumin is the main protein responsible for maintaining the osmotic pressure of the blood; with less albumin, the osmotic pressure of the blood decreased, which affected the osmotic gradient during tissue fluid formation and hence less water was taken back to the blood at the venule end, leaving it to accumulate in the surrounding tissues, hence the swelling of the lower limbs and fluid accumulation in body tissues observed in the affected children; **Ap**

ATP concentration in muscle cells, cellular metabolism and slow wound healing

ATP concentration in muscle cells was lower in affected children than in healthy children; **AI**, due to the swollen mitochondria, which reduced the efficiency of oxidative phosphorylation; **Ae**, the swollen mitochondria had damaged inner membranes and reduced cristae surface area, so the electron transport chain and ATP synthase could not

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function efficiently; this reduced oxidative phosphorylation and ATP production. ATP is required for cell division, protein synthesis, DNA replication and cell migration during wound repair; therefore, with less ATP available, skin epithelial cells and fibroblasts could not divide and migrate efficiently to replace damaged tissue, so wound healing was slow; the low ATP also reduced the activity of immune cells, so the children were less able to fight infections, which resulted in slow wound healing, frequent infections and persistent tiredness in the affected children; **Ap**

b) Providing a high-protein diet containing eggs and legumes for three weeks

It is effective; **EI**, providing a high-protein diet improves the children's health since eggs and legumes are rich sources of complete and complementary proteins, which provide amino acids for the synthesis of plasma albumin by the liver, raising the plasma albumin concentration and restoring the osmotic pressure of the blood, thereby reducing oedema and fluid accumulation in body tissues; however, a high-protein diet for only three weeks may not provide sufficient amounts to fully restore body mass and repair swollen mitochondria, and some children may have difficulty digesting and absorbing large amounts of protein if their gut lining is damaged; **Ee**, therefore, the high-protein diet should be implemented but it should be continued for longer than three weeks to fully recover; **Ep**

Giving concentrated glucose drinks as the main dietary treatment until body mass is restored

It is effective; EI, concentrated glucose drinks provide a rapid source of energy since glucose is easily absorbed and can be used immediately for ATP production, providing energy for cell division and fast repairing of tissues; however, tissue formation requires proteins and glucose drinks alone may increase the blood sugar levels, disrupting the blood osmotic potential; **Ee**, therefore, concentrated glucose drinks should be used but taken in moderate amounts; **Ep**

Visiting doctor's advice: giving a balanced diet containing proteins, carbohydrates, lipids, vitamins and mineral salts

It is effective; **EI**, a balanced diet provides all the necessary nutrients: proteins for the synthesis of plasma albumin and tissue repair, carbohydrates and lipids for energy and ATP production, vitamins and minerals for enzyme function, mitochondrial integrity and immune function; this comprehensive approach addresses the underlying causes of oedema, tiredness, slow wound healing and frequent infections; **Ee**. Therefore, the visiting doctor's advice should be implemented as the main long-term strategy, with food

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supplementation programmes, nutrition education for families, and therapeutic feeding for severely malnourished children until they recover. **Ep**

Item 7

a) **Functional DNA repair protein concentration, DNA damage and mutation accumulation**

Functional DNA repair protein concentration was lower in affected children compared to healthy children; **AI**, due to mutations in the *BRCA2* gene, which normally produces a protein involved in repairing double-strand breaks in DNA; **Ae**, the mutated *BRCA2* gene transcribed into an mRNA and upon translation produced a non-functional DNA repair protein, so double-strand breaks caused by ionising radiation were not repaired allowing mutations to accumulate in genes controlling the cell cycle, including tumour suppressor genes and proto-oncogenes; which resulted in the chromosomal abnormalities and fragmented nuclei observed in the abnormal white blood cells, contributing to the development of leukaemia in the affected children; **Ap**

RNA polymerase activity, transcription of growth-promoting genes and leukaemia

RNA polymerase activity was higher in affected children than in healthy children; **AI**, due to elevated levels of a transcription factor; **Ae**, the high RNA polymerase activity increased the transcription of genes that drive cell division and growth, forming growth proteins like tubulin proteins. Tubulin is the protein that forms microtubules, which make up the mitotic spindle required for chromosome separation during mitosis; the increased tubulin concentration supported the formation of more mitotic spindles, allowing more cells to progress through mitosis rapidly. This accelerated rate at which white blood cell precursors progressed through the cell cycle made more abnormal cells divide and accumulate in the bone marrow and blood, contributing to the high mitotic index in their bone marrow, hence the development of leukaemia; **Ap**

Rate of apoptosis, survival of abnormal cells and leukaemia

Rate of apoptosis in white blood cell precursors was lower in affected children than in healthy children; **AI**, due to mutations in genes controlling the cell cycle, including *TP53* and *BRCA2*, caused by prolonged exposure to ionising radiation and reduced DNA repair; **Ae**, apoptosis is the programmed cell death that normally eliminates cells with damaged DNA or abnormal cell cycle control; the low rate of apoptosis meant that abnormal white blood cell precursors survived instead of being destroyed, so they continued to divide and accumulated in the bone marrow and blood; which resulted in the high mitotic index, the

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accumulation of abnormal white blood cells and the development of leukaemia in the affected children; **Ap**

b) Relocate the community away from the mining site

It is effective; **EI**, it removes the source of prolonged exposure to ionising radiation from uranium mining waste, preventing further DNA damage in bone marrow cells and reducing the risk of new leukaemia cases and other radiation-related cancers; however, the contamination is already present in the environment, and families may still be exposed if they return to the area for farming or other activities; **Ee**, therefore, relocation should be implemented, combined with remediation of the contaminated site, and provision of alternative livelihoods and housing for the affected community; **Ep**

Use targeted chemotherapy to inhibit the overactive transcription factor

It is effective; **EI**, the drugs specifically inhibit the overactive transcription factor that promotes rapid cell division, slowing down the uncontrolled proliferation of abnormal white blood cell precursors and allowing normal blood cell production to recover; however, targeted chemotherapy may also affect normal rapidly dividing cells, causing side effects such as anaemia, increased risk of infection and bleeding; **Ee**, therefore, targeted chemotherapy should be implemented, with careful monitoring of side effects, supportive care and adjustment of drug regimens to reduce toxicity and prevent resistance; **Ep**

Establish a cancer registry to monitor long-term health outcomes in the community

It is effective; **EI**, this systematically collects data on cancer cases, including leukaemia and other radiation-related cancers, allowing early detection of trends, identification of high-risk groups and evaluation of the effectiveness of interventions; however, a cancer registry requires sustained funding, trained personnel and reliable data collection systems; **Ee**, therefore, the cancer registry should be implemented with remediation of the contaminated site and improved access to diagnosis and treatment, to easily curb it in case of fresh exposure; **Ep**

Item 8

a) Phenylalanine hydroxylase activity, phenylalanine metabolism and blood phenylalanine concentration

Phenylalanine hydroxylase activity was lower in Peter than the normal range; **AI**, due to a missense mutation in the *PAH* gene; **Ae**, the *PAH* gene was therefore transcribed into the wrong mRNA and, upon translation, a non-functional protein was produced, which resulted

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in a defective enzyme. The defective phenylalanine hydroxylase could not efficiently convert phenylalanine into tyrosine in the liver; as a result, phenylalanine was not metabolised normally and accumulated in the blood, which resulted in the higher blood phenylalanine concentration in Peter compared to the normal.

The failure to convert phenylalanine into tyrosine reduced the amount of tyrosine in the body for the synthesis of melanin, the pigment responsible for skin and hair colour; reduced melanin production led to unusually pale skin and hair observed in Peter compared to other family members; **Ap**

Due to the accumulation of phenylalanine in the blood, there was reduced relative transportation and uptake of other nutrients and amino acids by the brain cells, affecting their development and activities; hence the poor concentration and learning difficulties; **Ap**

The accumulation of phenylalanine exceeded the capacity of the normal metabolic pathway; excess phenylalanine was instead converted into phenylpyruvate by alternative metabolic pathways. Phenylpyruvate accumulated in the blood and was excreted in the urine, giving it an unusual musty smell, which resulted in the musty smell of Peter's urine; **Ap**

b) Diet free from phenylalanine

It is effective; **EI**, it prevents further accumulation of phenylalanine in the blood, reducing the toxic effects on the brain and preventing worsening of learning difficulties and poor concentration; however, phenylalanine is an essential amino acid, so a completely phenylalanine-free diet affects normal growth and development; **Ee**, therefore, a phenylalanine-restricted diet should be implemented under the supervision of a dietitian, with regular monitoring of blood phenylalanine levels and adjustment of intake to meet Peter's nutritional needs while preventing toxicity; **Ep**

Tyrosine supplements

It is effective; **EI**, they provide the tyrosine that Peter's body cannot synthesise from phenylalanine due to the defective phenylalanine hydroxylase, supporting the synthesis of melanin, thyroid hormones and neurotransmitters such as dopamine, which are important for normal skin and hair colour, metabolism and brain function; however, excessive tyrosine intake can cause its own side effects, such as nausea, headaches and irritability; **Ee**, therefore, tyrosine supplements should be implemented with regular monitoring of blood tyrosine levels to ensure they remain within the normal range; **Ep**

Gene therapy: introducing a functional copy of the affected gene into appropriate body cells

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It is effective; **EI**, it introduces a functional copy of the *PAH* gene into his liver cells, restoring the production of functional phenylalanine hydroxylase, which would allow normal conversion of phenylalanine into tyrosine and prevent the accumulation of toxic phenylalanine and phenylpyruvate; however, gene therapy may have off-target effects and requires efficient delivery systems to reach the liver cells; **Ee**, therefore, gene therapy should be maintained, but further research and clinical trials should be done to ensure proper targeting and full transformation; **Ep**

Item 9

a) Individual X1

Traces of cordycepin and actinomycin D were found in Individual X1; **AI**, attributed to the factory discharging its untreated wastes into the water source used by the family; **Ae**, cordycepin causes premature chain termination of mRNA, while actinomycin D inhibits RNA polymerase which slows down the rate of DNA transcription resulting in to fewer complete mRNA molecules formed to serve as templates in translation; very few polypeptides are synthesized, hence delayed skin healing; **Ap**

Traces of cyanide were found in Individual X1; **AI**, attributed to the factory discharging untreated wastes containing cyanide into the water source; **Ae**, cyanide non-competitively inhibited cytochrome c oxidase enzyme interfering with transfer of electrons to oxygen/ hydrogen atoms to oxygen, hydrogen atoms accumulate, ceasing aerobic respiration hence lower ATP generated which reduces active uptake of nutrients, activation of amino acids in protein synthesis decreasing biosynthesis which resulted in delayed skin healing and muscle tiredness; **Ap**

Traces of heavy metals like arsenic were found in Individual X1, coupled with cancerous tumours in his colon; **AI**, attributed to the factory discharging untreated wastes containing these substances into the domestic water source; **Ae**, arsenic caused mutations in essential genes such as tumour suppressor genes, and proto-oncogenes to transform into oncogenes, and proteins coded for after the mutations resulted in abnormal cell behaviour and division forming cancerous tumours in the colon hence pain in the lower abdominal region; **Ap**

Individual X2

Membrane fluidity is lower in individual X2 than in normal person; **Al** attributed to the factory discharging untreated wastes that interfered with the synthesis of membrane lipids and presence of only saturated membrane lipid tails; **Ae**; saturated tails are straight and closely pack together lowering membrane fluidity which reduced the movement of carrier proteins and the transport of amino acids into the cells hence the absence of amino acids

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P(tryptophan) and Q (tyrosine) in gastric gland cells and pancreatic acinar cells. This interfered with normal protein synthesis forming fewer digestive enzymes which slowed down food digestion in the stomach and duodenum; fewer respiratory substrates are availed leading to lower ATP production, hence body weakness; **Ap**

b) For individual X1

Use of aphidicolin, which inhibits DNA polymerase,

It is **effective**; **EI**, aphidicolin inhibits DNA polymerase, which is required for DNA replication, so cancer cells cannot replicate their DNA, get stalled in the S phase and cannot complete the cell cycle, however, it works as a reversible competitive inhibitor whose effect is concentration dependent; **Ee** therefore, the drug should be given following prescribed intervals to ensure complete inhibition; **Ep**

Chemotherapy treatment

It is effective; **EI**, it targets and kills all dividing cancer cells including metastatic ones by blocking DNA replication and enzyme production interfering with mitosis, reducing the tumour mass and relieving the lower abdominal pain; however, chemotherapy also affect normal rapidly dividing cells such as those in the bone marrow, and hair follicles, causing side effects such as anaemia, hair loss and increased risk of infection; **Ee**, therefore, the strategy should continue but with bone marrow transplant and careful monitoring of blood cell counts, ; **Ep**

For individual X2

Diet rich in amino acids (tryptophan and tyrosine) for Individual X2

It is **effective**; **EI**, the diet provides the amino acids his gastric gland cells and pancreatic acinar cells lacked, allowing the cells to synthesise the proteins including digestive enzymes enhancing food digestion in the stomach and duodenum relieving the body weakness; however, it further increases the blood amino acid concentration due to lower membrane fluidity, which impairs their uptake in to the cells resulting into higher rate of urea production from deamination and weight gain; **Ee**, therefore, the strategy should continue but coupled with improvement of membrane fluidity through dietary unsaturated fats, and monitoring of blood amino acid levels to ensure adequate absorption; **Ep**

ASSESSMENT OBJECTIVE 2: PLANT PHYSIOLOGY AND ADAPTATION

Item 1

a) Leaf chlorophyll concentration, light absorption and photosynthetic efficiency

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Leaf chlorophyll concentration was lower in affected pineapples than in normal pineapples; **AI**, due to repeated cropping, which greatly reduced available nitrogen in the soil; **Ae**, nitrogen is essential for chlorophyll synthesis in leaves, the low nitrogen availability reduced chlorophyll synthesis, so the leaves contained less chlorophyll and appeared pale or yellowish, therefore less light energy was absorbed needed in photolysis to form light depend products like ATP and Reduced NADP that are needed in the reduction step of the light dependent stage which led to a lower photosynthetic efficiency in the affected pineapples compared to the normal resulting in reduced carbohydrate production, poor growth and lower fruit production in the affected pineapples; **Ap**

Stomatal conductance, gas exchange and photosynthetic efficiency

Stomatal conductance was lower in affected pineapples compared to the normal pineapples; **AI**, due to the higher temperatures and irregular rainfall, **Ae**, these caused heat and water stress that stimulated production of abscisic acid, which induced stomatal closure in the pineapple plants to reduce water loss through transpiration; however, this stomatal closure reduced the entry of carbon dioxide into the leaves, so less CO_2 was available for fixation in the Calvin cycle; this reduced the rate of carbon fixation and carbohydrate synthesis, lowering the photosynthetic efficiency in normal pineapples. This resulted in reduced carbohydrate production, poor growth and lower fruit production in the affected pineapples; **Ap**

Rate of flowering, photoperiod and fruit production

Rate of flowering was lower in affected pineapples than in normal pineapples; **AI**, due to farmers shifting planting times to utilise the early rains; **Ae**, the plants experienced a day length of 13 hours instead of the 10 hours that the local pineapple variety normally receives. This therefore reduced the nighttime needed to convert the phytochrome far-red to phytochrome red that accumulates during the day, leading to accumulation of phytochrome far-red since its conversion to red is slow and this inhibited the production of florigen hormone that induces opening of flower buds, so fewer plants initiated flowering and, with fewer plants flowering, fewer fruits were produced, resulting in reduced crop productivity in the affected pineapples; **Ap**

b) Apply organic manure and other appropriate nutrient-replacement practices

It is effective; **EI**, organic manure replenishes soil nitrogen and other nutrients that were depleted by repeated cropping, providing the nitrogen needed for chlorophyll synthesis, so leaf chlorophyll concentration increases, more light energy is absorbed, and photosynthetic

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efficiency improves, leading to higher carbohydrate production and better fruit yield; however, organic manure releases nutrients slowly, which delays restoration of chlorophyll deposition, and excessive application can cause nutrient imbalance; **Ee**, therefore, it should be implemented with regular soil testing to determine the correct type and amount of fertilizer needed; **Ep**

Use mulching and water-conservation practices during dry periods

It is effective; **EI**, mulch reduces evaporation from the soil surface, conserving moisture around the pineapple roots and lowering soil temperature, which reduces heat and water stress; better soil moisture keeps stomata open for longer, allowing continued CO_2 uptake and photosynthesis, so photosynthetic efficiency and carbohydrate production improve, supporting better growth and fruit production; however, thick mulch may harbour pests and increased moisture causes fungal diseases if poorly managed; **Ee**, therefore, it should be implemented with less mulch and regular monitoring for pests and diseases; **Ep**

Adjust planting dates to match the crop's suitable photoperiod and seasonal conditions

It is effective; **EI**, this ensures that the pineapple plants experience the short day length of about 10 hours that the local variety requires for flowering, rather than the 13-hour day length caused by early planting, inducing flowering in a higher proportion of plants, so the rate of flowering and fruit production increases; however, adjusting planting dates depends on the reliability of seasonal rainfall, and unpredictable weather patterns may make it difficult to match planting to the ideal photoperiod and moisture conditions; **Ee**, therefore, adjusting planting dates should be implemented with weather forecasting and extension advice; **Ep**

Item 2

a) Soil water content, photosynthetic rate and grain yield

Soil water content was lower in the affected field than in the healthy field; **AI**, due to the absence of irrigation, mulch, and soil cover which increased water loss by evaporation; **Ae**, as the soil dried, this reduced the amount of water available for the light-dependent stage for photolysis to release electrons that replace the electrons lost from photosystem II. This therefore reduces the production of light-dependent products like reduced NADP and ATP that are needed in the reduction phase, reducing the amount of sugars formed in the light-independent stage. This reduced the amount of substrates available for the process of

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respiration needed to produce energy for plant growth, hence the lower mean plant height and grain yield in the affected field; **Ap**

Stomatal conductance, photosynthetic rate and grain yield

The affected maize plants had a lower stomatal conductance compared to the maize in the healthy field; **AI**, due to the prolonged dry spell and therefore plants relied on rainfall; **Ae**, this caused water stress, inducing production of abscisic acid (ABA), whose concentration increased in the leaves; ABA travelled to the guard cells reducing stomatal aperture to reduce water loss through transpiration and this led to a lower stomatal conductance in the affected field than in the healthy field reducing carbon dioxide uptake which reduced the internal CO_2 concentration, reducing the rate of carbon fixation by RuBisCO in the Calvin cycle which resulted in reduced carbohydrate production, poor plant growth and low grain yield in the affected field; **Ap**

b) Use of irrigation

It is effective; **EI**, it replenishes soil water content during dry periods, reducing the water deficit that triggers ABA production; therefore, with adequate soil moisture, stomata remain open, CO_2 uptake continues, and the rate of photosynthesis increases, providing more carbohydrates for plant growth and grain filling; however, excessive irrigation increases the amount of moisture on the plant, which encourages fungal growth, leading to fungal diseases that may affect the yields; **Ee**, therefore, irrigation should be implemented, but moderate amounts of water should be used to prevent excess moisture; **Ep**

Use of mulching

It is effective; **EI**, Mulching covers the soil surface and reduces evaporation, conserving soil moisture during dry periods; better soil moisture reduces ABA production and keeps stomata open for longer, supporting continued CO_2 uptake and photosynthesis, which increases carbohydrate production for plant growth; however, thick mulch may harbour pests or fungal diseases if poorly managed; **Ee**, therefore, mulching should be done but with less mulch and with regular monitoring for pests and diseases; **Ep**

Wider plant spacing

It is effective; **EI**, this reduces competition between maize plants for soil water, nutrients and light; with fewer plants per unit area, each plant has access to more water and nutrients, so the water deficit is reduced; however, encourages water loss and it may also allow more weeds to grow; **Ee**, therefore, wider plant spacing should be implemented, but the optimum

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density should be determined by local conditions, and with weed control to prevent competition; **Ep**

Drought-tolerant C4 maize varieties

It is effective; **EI**, drought-tolerant C4 maize varieties improve productivity as they minimise photorespiration through efficient carbon fixation even when stomata are partially closed under drought stress; however, drought-tolerant varieties may lose their traits over generation with cross pollination; **Ee**, therefore, this should be implemented with refuge planting and and local seed banks; **Ep**

Item 3

Net photosynthetic rate, carbohydrate production and crop yield

Net photosynthetic rate was lower in beans than in maize; **AI**, due to the high temperature; **Ae**, beans are C_3 plants, so under high temperature and intense light, photorespiration is encouraged where RuBisCO binds to oxygen instead of carbon dioxide, wasting energy and reducing net carbon fixation and therefore less carbohydrates were produced for growth, flowering which resulted in a lower mean crop yield in beans compared to maize; **Ap**

Stomatal conductance, water loss and seedling survival

Mean stomatal conductance was higher in beans than in maize; **AI**, due to the lower CO_2 fixation efficiency at high temperature and in saline soil around the Salt Lake; **Ae**, this caused excessive water loss through transpiration, leading to dehydration and wilting; in saline soils, high water loss concentrates salts in the root zone, causing further osmotic stress that reduces water uptake; inducing production of abscisic acid (ABA), whose concentration increased in the leaves promoting stomatal closure which lowered stomatal conductance in the bean than in the maize reducing carbon dioxide uptake which reduced the internal CO_2 concentration, reducing the rate of carbon fixation by RuBisCO in the Calvin cycle which resulted in reduced carbohydrate production, poor plant growth and low grain yield in the beans; **Ap**

b) Establishment of salt-tolerant vegetation around the Salt Lake

It is effective; **EI**, salt-tolerant plants absorb excess salts from the soil. This increases the solute concentration of the cell sap, which encourages water absorption by osmosis due to an osmotic gradient created, hence availing a raw material for photosynthesis; however, establishing such vegetation takes time and may compete with crops for water and

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nutrients; **Ee**, therefore this strategy should be done ensuring that the vegetation is established far from the crops to prevent competition; **Ep**

Irrigation using water obtained away from the Salt Lake

It is effective; **EI**, it dilutes soil salts and leaches them below the root zone, reducing osmotic stress on bean plants and improving water availability for photosynthesis and growth; adequate water also helps maintain stomatal conductance at an optimal level, allowing CO_2 uptake for photosynthesis while preventing excessive water loss; however, excessive irrigation can waterlog the soil or raise the water table, causing secondary salinisation; **Ee**, therefore, this strategy should be implemented with efficient irrigation methods such as drip irrigation, combined with proper drainage to avoid waterlogging and secondary salinisation; **Ep**

Introduction of crop varieties with improved tolerance to salinity and high temperature

It is effective; **EI**, tolerant varieties can maintain higher photosynthetic rates, better stomatal regulation and improved seedling survival under saline and high-temperature conditions, ensuring stable yields even when beans are less suited to the environment; however, improved varieties may lose their salt-tolerance and heat-tolerance traits over successive generations if grown without controlled crossing, because the genes controlling ion compartmentation, osmotic adjustment and heat-stable enzymes may be diluted or segregated out; **Ee**, therefore, it should be implemented but with government subsidies, local seed multiplication and farmer training; **Ep**

Item 4

a) Photosynthetic rate, carbohydrate production and vegetative growth

Photosynthetic rate was lower in tomato than in maize; **AI**, this is because beans use a C_3 pathway; **Ae**, their pathway is less efficient under high temperature and intense light because RuBisCO binds oxygen instead of carbon dioxide, causing photorespiration, which wastes energy and reduces net carbon fixation; this reduces the amount of carbohydrates available for respiration to produce energy needed in cell division of the plant cells and growth, resulting in a lower mean vegetative growth in beans compared to maize and reduced crop yield; **Ap**

Gibberellin activity, cell elongation and vegetative growth

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Gibberellin activity in shoot tips was lower in tomato than in maize; **AI**, due to the high temperature and limited water availability in Buginyanya; Ae, the high temperatures inhibited release of gibberellins, which lowered the gibberellin activity, reducing cell elongation, so internodes remained short, stems elongated poorly and leaves expanded slowly; this limits the plant's height and leaf area, reducing light interception and the photosynthetic surface area, leading to less carbohydrate production for vegetative growth and fruit development; **Ap**

Ethylene production, leaf abscission and crop yield

Ethylene production during fruit development was higher in tomato than in maize; **AI**, due to the stress conditions of high temperature and limited water availability, combined with active fruit development in tomato; **Ae**, high ethylene levels promote leaf abscission, inhibiting cell division and elongation in the leaves, which causes early leaf senescence and leaf fall, which reduces surface area for sunlight absorption needed in the light-dependent stage to cause photolysis producing products like ATP and reduced NADP that are needed in the dark stage to fix carbon to form sugars important in growth. This therefore reduces cell division in the leaves, hence lower mean vegetative growth, and therefore fewer sugars are stored, hence a lower crop yield in the tomato; **Ap**

b) Introduction of heat-tolerant tomato varieties

It is effective; **EI**, heat-tolerant varieties can maintain higher photosynthetic rates, better fruit set and reduced flower drop under high-temperature conditions, ensuring stable yields even when temperatures are high; however, they may require repeated purchase if they are hybrids since factors like cross-pollination may affect the crop variety; **Ee**, therefore, this should be done only with government subsidies and local seed multiplication to ensure accessibility; **Ep**

Irrigation during the hot periods of the day to reduce heat and water stress

It is **effective**; **EI**, this avails water and adequate water reduces heat and water stress which reduces the inhibition on gibberellin production encouraging cell elongation and hence more vegetative growth, increased surface area for photosynthesis, more sugar production and hence increased crop yield; however, irrigation during the hot period of the day encourages water loss from the plant through transpiration which increases water stress in turn; **Ee**, therefore, irrigation should be implemented with efficient water-saving methods such as drip irrigation and mulching, and timed for early morning or late evening to minimise evaporation losses, rather than during the hottest periods of the day; **Ep**

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Adjustment of planting dates so that sensitive stages of tomato development occur during relatively cooler and wetter periods

It is effective; **EI**, planting at times when temperatures are cooler and rainfall is more reliable allows sensitive stages such as flowering and fruit development to escape heat and water stress, reducing flower drop, premature ripening and yield losses; however, changing planting dates may expose the crop to other pests or diseases that peak at different times; **Ee**. therefore, adjusting planting dates should be implemented alongside weather forecasting and pest monitoring; **Ep**

Item 5

a) Germination rate, early seedling establishment and crop survival

Germination rate was lower in Variety B than in Variety A; **AI**, due to Variety B having a lower ratio of gibberellins to abscisic acid in its seeds; **Ae**, gibberellins promote the breakdown of DELLA proteins, which removes the inhibition of release of the germination enzymes. With fewer gibberellins produced, fewer enzymes were produced, reducing the breakdown of stored food to produce energy needed for cell division and elongation in the embryo, while abscisic acid maintains dormancy and inhibits germination; hence, fewer seedlings emerged and those that did were weaker; this reduced early seedling establishment, making the plants more vulnerable to high temperatures and low soil moisture in the semi-arid region, which resulted in lower crop survival in Variety B compared to Variety A; **Ap**

Mean vegetative growth index, leaf development and crop yield

Mean vegetative growth index was lower in Variety B than in Variety A; **AI**, due to Variety B having a lower concentration of cytokinins in its young shoots; **Ae**, cytokinins promote cell division and leaf development, so the low cytokinin concentration in Variety B reduced leaf formation and expansion, resulting in small yellowish leaves, which reduced surface area for sunlight absorption needed in the light-dependent stage of photosynthesis, hence a lower net photosynthetic rate in Variety B compared to Variety A. This reduced carbohydrate production, so the plant could not accumulate enough assimilates for flowering and yield, resulting in lower crop yield in Variety B compared to Variety A; **Ap**

b) Seed priming or appropriate pre-sowing treatments to improve germination and early establishment

It is effective; **EI**, seed priming improves the growth, productivity and climate resilience of Variety B since it hydrates seeds under controlled conditions before sowing, raising the

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gibberellin-to-abscisic acid ratio and promoting faster, more uniform germination, which improves early seedling establishment even in Variety B; however, primed seeds cannot be stored for long periods, so the method must be repeated each season; **Ee**, therefore, seed priming should be implemented with farmer training on proper priming techniques, access to good-quality seed; **Ep**

Supplementary irrigation and soil-moisture conservation during periods of severe water stress

It is effective; **EI**, supplementary irrigation and soil-moisture conservation improve the growth, productivity and climate resilience of Variety B since they reduce water stress, maintain stomatal opening for CO_2 uptake, support photosynthesis and improve the supply of assimilates for vegetative growth and grain filling; however, excessive irrigation may cause leaching of nutrients like magnesium which reduces its availability to the plants leading to chlorosis, reduced sunlight absorption and hence poor growth and the use of thick mulches as soil moisture conservation measures may harbour pests; **Ee**, therefore, this strategy should be implemented but with use of moderate amounts of water and less mulch; **Ep**

Introduction or breeding of varieties with greater tolerance to high temperature and drought

It is effective; **EI**, tolerant varieties can maintain higher photosynthetic rates, better stomatal regulation, and improved seedling establishment under high temperature and low soil moisture, ensuring stable yields even in the semi-arid region; however, breeding new varieties takes time, and they may lose their tolerance traits over successive generations if grown without controlled crossing; **Ee**, therefore, this strategy should be implemented through government and research institution partnerships, with local seed multiplication and field monitoring to maintain the tolerance traits; **Ep**

Item 6

a) Stem height and vegetative growth, vegetative growth and competition

Stem height and vegetative growth were lower in maize than in weeds; **AI**, due to high gibberellin and cytokinin concentrations in the weed shoot tips; **Ae**, gibberellins promote cell elongation, while cytokinins promote cell division and leaf development; these hormones in weed seedlings enabled rapid stem elongation and leaf expansion hence, weeds grew faster and taller than the maize; the taller weed seedlings therefore competed

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favorably for sunlight while shading the maize which reduced their sunlight absorption, reducing activities in the light dependent stage, which resulted in a lower photosynthetic rate in maize compared to weeds, contributing to poor maize grain yield; **Ap**

ABA concentration in maize leaves, stomatal conductance and photosynthetic rate

ABA concentration in leaves was higher in maize than in weeds; **AI**, due to heat and moisture stress in the Nakasongola District, to which the maize was more sensitive than the heat-tolerant weeds; **Ae**, drought reduced water availability to the maize, which induced production of ABA, increasing its concentration in maize that caused stomatal closure, which resulted in a lower stomatal conductance in the maize compared to the weeds. Stomatal closure restricted the entry of carbon dioxide into the leaves, so less CO_2 was available for fixation in the Calvin cycle, lowering the photosynthetic rate in the maize, hence the poor maize grain yield; **Ap**

b) Apply irrigation and mulch to reduce drought and heat stress on the maize

It is **effective**; **EI**, irrigation replenishes soil water content, reducing the water deficit that triggers ABA production; with adequate soil moisture, stomata remain open, CO_2 uptake continues, and the photosynthetic rate increases, providing more carbohydrates for vegetative growth and mulch reduces evaporation from the soil surface, conserves moisture, lowers soil temperature and suppresses weeds, reducing competition for water and nutrients; however, excessive irrigation increases moisture around the plant which may encourage fungal attack and use of thick mulching materials may harbour pests and fungal diseases; **Ee**, therefore, irrigation and mulching should be implemented using moderate amounts of water and mulch to reduce on the chances of fungal growth; **Ep**

Avoid bush burning and instead incorporate crop residues into the soil to suppress weed seed germination

It is effective; **EI**, crop residues cover the soil surface, suppressing weed seed germination by reducing light and creating a physical barrier; this reduces weed competition for water, nutrients and light, allowing the maize to grow more vigorously and produce higher yields. Incorporating residues also adds organic matter to the soil, improving soil fertility, water-holding capacity and nutrient availability; however, thick residues harbour pests that may attack the crops, and these also increase moisture content and provide substrates for fungal growth leading to fungal diseases; **Ee**, therefore, this strategy should be implemented with farmer training on residue management, and with regular monitoring for pests and diseases; **Ep**

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Regulate the use of auxin-based herbicides to prevent drift onto the maize crop

It is effective; **EI**, this prevents the herbicide from drifting onto the maize crop, avoiding the abnormal twisting, epinasty and stunted growth caused by disruption of normal auxin gradients in the shoot tips; this allows the maize to grow normally, flower properly and produce higher grain yields; however, regulation requires training, supervision and enforcement which farmers may not have; **Ee**, therefore, this strategy should be implemented with farmer training on safe herbicide application; **Ep**

Use drought-tolerant maize varieties with stable hormone responses

It is effective; **EI**, such varieties maintain lower ABA concentrations under drought stress, keeping stomata open for longer and maintaining higher photosynthetic rates, supporting better vegetative growth and hence high productivity under dry conditions; however, they may also lose their tolerance traits over successive generations if grown without controlled crossing; **Ee**, therefore, drought-tolerant maize varieties should be implemented with farmer training and field monitoring to maintain the tolerance traits; **Ep**

Item 7

a) Pfr: Pr ratio, photoperiodic induction and rate of flowering

The Pfr:Pr ratio at the end of the night was higher in Group A than in Group B; **AI**, due to the streetlights remaining on throughout the night from 8 pm to 5 am, giving Group A a day length of 21 hours and a night length of only 8 hours; **Ae**, in photoperiodism, phytochrome exists in two interconvertible forms: Pr (inactive form) and Pfr (active form); during the day, red light converts Pr to Pfr, while during darkness, Pfr slowly reverts to Pr; a long uninterrupted night allows Pfr to fall to a low level, which is the signal that induces flowering in short-day plants such as poinsettia; in Group A, the continuous light from streetlights prevented Pfr from reverting to Pr, so the Pfr:Pr ratio remained high at the end of the night inhibiting production of florigen hormone to trigger flowering which resulted in a low rate of flowering in Group A compared to Group B; **Ap**

Chlorophyll concentration, light absorption and crop yield

Chlorophyll concentration was lower in Group A than in Group B; **AI**, due to prolonged light exposure from the streetlights, which damaged chlorophyll and reduced its synthesis; **Ae**, the prolonged exposure to light caused chlorophyll damage through photo-oxidation; with less chlorophyll, Group A absorbed less light energy, so the rate of photophosphorylation and the production of ATP and NADPH were reduced; this lowered the rate of carbon fixation in the Calvin cycle and reduced carbohydrate production reducing supply of the

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resources for flower initiation, flower development and the formation of flower heads which resulted in a lower crop yield in Group A compared to Group B; **Ap**

Wilting rate, water stress and flowering

Wilting rate was higher in Group A than in Group B; **AI**, due to Group A being grown without mulch and the higher environmental temperature in Group A compared to Group B; **Ae**, the higher temperature and lack of mulch increased evaporation from the soil surface and transpiration from the leaves, causing water stress which induced the plant to produce abscisic acid (ABA), which causes stomatal closure and reduces CO_2 uptake for photosynthesis. This reduced carbohydrate production needed as substrates for respiration to produce energy needed for cell division in the flower buds resulted in a low rate of flowering and low crop yield in Group A compared to Group B; **Ap**

b) Install light-proof screens or curtains around the greenhouse at night

It is effective; **EI**, it blocks the light from streetlights during the night, allowing Pfr to revert to Pr and restoring the long uninterrupted dark period required to induce flowering in this short-day plant; this increases the rate of flowering and the number of flower heads produced; however, light-proof screens may reduce ventilation, increasing humidity and the risk of fungal diseases if not properly designed; **Ee**, therefore, light-proof screens or curtains should be implemented with proper ventilation and humidity control; **Ep**

Use low-intensity red/far-red LED flashes at specific times

It is effective; **EI**, far-red light converts Pfr back to Pr, artificially lowering the Pfr:Pr ratio at the end of the night and simulating the effect of a long dark period; this can induce flowering even when complete darkness is not possible, allowing growers to manage flowering under these light conditions; however, LED systems with high intensity may disrupt flowering rather than promote it; **Ee**, therefore, LED flashes should be implemented with intensity control and regular monitoring of the Pfr:Pr ratio; **Ep**

Apply shading nets during the day

It is effective; **EI**, shading reduces light intensity and temperature, protecting chlorophyll from damage caused by prolonged light exposure which supports better photosynthesis and carbohydrate production for flowering; however, shading nets may reduce light intensity too much, limiting photosynthesis if the shade is too dense; **Ee**, therefore, shading nets should be implemented with an appropriate shade level that reduces heat and light stress without limiting photosynthesis too much; **Ep**

Use mulching and irrigation

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It is effective; **El**, mulch reduces evaporation from the soil surface, conserving moisture around the roots and lowering soil temperature, while irrigation replenishes soil water content during dry periods; together, they reduce water stress, keep stomata open for CO_2 uptake, support photosynthesis and increase carbohydrate production for flower initiation and development; however, thick mulch and excessive irrigation encourage fungal growth and fungal diseases; **Ee**, therefore, mulching and irrigation should be implemented with moderate amounts of mulch and water to reduce the moisture content; **Ep**

ASSESSMENT OBJECTIVE 3: ANALYSES ANIMAL SYSTEMS AND BEHAVIOURS IN ADAPTING TO ENVIRONMENTAL CHANGES FOR HEALTH, SURVIVAL, AND WELFARE.

Item 1

a) ADH concentration, water conservation and feeding success rate

ADH concentration was higher in affected crocodiles than in normal crocodiles; **Al**, it is attributed to the unusually prolonged dry spell that caused Nile water levels to drop sharply, leaving only a few shallow pools; **Ae**, daytime temperatures frequently exceeded 42°C, causing higher rates of water loss from the crocodiles' bodies through evaporation from the skin and gaping, which increased the osmotic pressure of the blood; this was detected by osmoreceptors in the hypothalamus, stimulating increased secretion of ADH, which increased the permeability to water of the walls of the distal convoluted tubule (DCT) and collecting duct (CD) to enhance water reabsorption and conserve more water; however, the scarcity of water sources also forced many crocodiles to move in coordinated groups and travel longer distances in search of deeper pools, which reduced foraging time and brought them through unfamiliar areas where encountered more predators and human settlements, increasing the risk of injury and death resulting in a lower feeding success rate in affected crocodiles compared to normal crocodiles; **Ap**

Core body temperature, thermoregulation and feeding success rate

Core body temperature was higher in affected crocodiles than in normal crocodiles; **Al**, due to daytime temperatures frequently exceeded 42°C; **Ae**, higher temperatures caused warming of the remaining shallow water and increasing heat absorption by the crocodiles from the air by radiation and from the warm water by conduction forced many crocodiles to spend more time gaping and seeking shade to avoid overheating, thereby reducing time spent hunting; also, more energy was diverted from growth and reproduction to thermoregulation, and the elevated core body temperature reduced enzyme activity, making

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the crocodiles lethargic and less able to capture prey; which resulted in a lower feeding success rate in affected crocodiles compared to normal crocodiles; **Ap**

Visibility, hunting ability and feeding success rate

Visibility was lower in affected crocodiles than in normal crocodiles; **Al**, this is attributed to smoke from seasonal bush fires; **Ae**, the thick smoke reduced visibility during daytime, subjecting the crocodiles to a higher risk of failed hunts since they are visual ambush predators that rely on detecting prey by sight before striking; it also interfered with their ability to detect predators and competitors, increasing the risk of injury and reducing their ability to defend suitable basking and nesting sites, which resulted in a lower feeding success rate in affected crocodiles compared to normal crocodiles; **Ap**

b) Constructing artificial water pans and maintaining deeper pools during dry seasons

It is effective; **El**, artificial water pans and deeper pools increase the availability of reliable fresh water during the dry season, reducing dehydration and lowering ADH concentration; deeper pools also have lower water temperatures and higher dissolved oxygen levels, helping the crocodiles maintain a core body temperature closer to the optimal range and reducing heat stress. Better water availability and lower heat stress allow the crocodiles to spend more time hunting and less time seeking shade, improving feeding success and energy reserves for reproduction; however, poorly designed water pans may become breeding grounds for disease or attract human-wildlife conflict; **Ee**, therefore, the strategy should continue but coupled with monitoring of water quality, combined with protection of existing natural pools; **Ep**

Controlling bush burning around the park

It is effective; **El**, controlling bush burning reduces the smoke that lowers visibility along the riverbanks, allowing the crocodiles to detect and capture prey more effectively; better visibility also helps them detect predators and competitors and defend suitable basking and nesting sites; however, controlling bush burning requires enforcement, community engagement and it may be difficult to control natural fires during the dry season; **Ee**, therefore, the strategy should continue but coupled with community education and controlled burning programmes; **Ep**

Creating protected basking and nesting sites away from human settlements

It is effective; **El**, protected basking and nesting sites reduce competition for suitable basking sites and provide safe undisturbed areas for nesting allowing the crocodiles to regulate their body temperature behaviourally, helping them maintain a core body

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temperature closer to the optimal range; protected nesting sites reduce the risk of nest destruction by humans, livestock or predators, and reduce human-wildlife conflict by keeping crocodiles away from human settlements; however, creating and protecting these sites requires land, fencing, regular monitoring and enforcement, and may displace other wildlife or conflict with local land use; **Ee**, therefore, the strategy should continue but coupled with community engagement, clear boundary demarcation and regular monitoring; **Ep**

Item 2

a) Blood oxygen saturation, tissue oxygenation and physical performance score

Blood oxygen saturation was lower in affected miners than in normal miners; **AI**, it is attributed to carbon monoxide fumes released by poorly maintained generators, which the miners inhaled during underground work; **Ae**, carbon monoxide combined with haemoglobin with a much higher affinity than oxygen, forming carboxyhaemoglobin and reducing the amount of haemoglobin available to carry oxygen; this reduced the oxygen saturation of the blood and the delivery of oxygen to the tissues, including skeletal muscles and the brain; with less oxygen available, aerobic respiration in muscle cells was reduced, so less ATP was produced for muscle contraction, causing weakness and reduced physical performance. The reduced oxygen supply to the brain also slowed down nervous coordination, which resulted in a lower physical performance score in affected miners compared to normal miners; **Ap**

Reaction time to stimulus, nervous coordination and survival rate

Reaction time to stimulus was higher in affected miners than in normal miners; **AI**, it is attributed to use of local anaesthetics and hypothermia caused by prolonged contact with cold groundwater and damp air; **Ae**, local anaesthetic drugs blocked sodium ion channels in nerve cell membranes, which reduced the movement of sodium ions into the axoplasm needed to cause depolarization and development of an action potential, slowing down impulse transmission. Hypothermia slowed synaptic transmission by reducing the kinetic energy of the neural transmitter needed for diffusion along the synaptic cleft and that of the ions in ionic exchange, further slowing down impulse transmission. The slower nervous coordination meant the miners could not respond quickly to environmental hazards such as falling rocks, flooding, or equipment failure, which resulted in a lower survival rate in affected miners compared to normal miners; **Ap**

Core body temperature, enzyme activity and physical performance score

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Core body temperature was lower in affected miners than in normal miners; **AI**, due to prolonged contact with cold groundwater and damp air; **Ae**, which caused excessive heat loss from the miners' bodies by conduction and convection; the low core body temperature reduced the rate of enzyme-controlled metabolic reactions in the muscles and nerves, so less ATP was produced for muscle contraction and nervous coordination; the miners also experienced violent shivering, which consumed large amounts of ATP and glucose, further reducing the energy available for physical work, which resulted in a lower physical performance score in affected miners compared to normal miners; **Ap**

b) Wearing additional layers of clothing

It is effective; **EI**, wearing additional layers of clothing reduces heat loss from the body by trapping a layer of still air between the clothing and the skin, which acts as an insulator and reduces heat loss by conduction and convection; this helps the miners maintain a core body temperature closer to the normal range, supporting enzyme activity, muscular coordination and physical performance; however, additional clothing can become damp from cold groundwater and sweat, which reduces its insulating properties and may increase heat loss by conduction; it may also restrict movement and make physical tasks more difficult; **Ee**, therefore, the strategy should continue but with waterproof and moisture-wicking insulated clothing, and miners should change out of damp clothing; **Ep**

Working in groups

It is effective; **EI**, working in groups increases protection against underground hazards through improved vigilance and mutual assistance; if one miner becomes dizzy, hypothermic or disoriented, the others can provide immediate help, call for assistance or evacuate the affected miner to the surface, reducing the risk of death from hypothermia or carbon monoxide poisoning; however, working in groups may increase competition for limited safe areas, and crowded groups may increase the risk of accidents if coordination is poor; **Ee**, therefore, the behaviour should continue but with smaller, well-coordinated groups, clear communication protocols, and regular monitoring of each miner's condition; **Ep**

Reducing undergro und activities during the coldest periods

It is effective; **EI**, reducing underground activities during the coldest periods reduces the duration of exposure to cold groundwater and damp air, lowering heat loss from the body and helping miners maintain a core body temperature closer to the normal range; this reduces the risk of hypothermia and its effects on enzyme activity, muscular coordination

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and physical performance; however, reducing underground activities lowers productivity and keep them in one place, which increases their continued exposure to the carbon monoxide fumes; **Ee**, therefore, the behaviour should continue but combined with improved underground ventilation and work schedules should be adjusted to allow recovery periods in warmer areas; **Ep**

Improving underground ventilation to prevent carbon monoxide accumulation

It is effective; **EI**, improving underground ventilation reduces the accumulation of carbon monoxide from poorly maintained generators, lowering the formation of carboxyhaemoglobin and restoring blood oxygen saturation. This improves oxygen delivery to the muscles and brain, supporting aerobic respiration, ATP production, physical performance and faster reaction times; however, poorly designed systems may create uneven airflow that leaves some areas still contaminated; **Ee**, therefore, the strategy should continue but coupled with regular monitoring of carbon monoxide levels and air quality; **Ep**

Providing insulated clothing and emergency thermal blankets for all miners

It is effective; **EI**, insulated clothing reduces heat loss by trapping still air, and emergency thermal blankets provide immediate warmth for miners showing signs of hypothermia, helping to restore core body temperature and prevent further heat loss; this supports enzyme activity, muscular coordination and physical performance; however, insulated clothing can become damp and lose its insulating properties, and thermal blankets are only effective if used promptly and correctly; **Ee**, therefore, the strategy should continue but with waterproof and moisture-wicking materials, regular replacement of damaged clothing and training on the correct use of thermal blankets; **Ep**

Conducting pre-shift medical screening for miners recovering from surgery or anaesthesia

It is effective; **EI**, pre-shift medical screening identifies miners who are still experiencing the effects of local anaesthetic drugs or are recovering from surgery, so they can be excluded from underground work until they have fully recovered; this reduces the risk of delayed responses, dizziness and hypothermia in miners whose nervous systems are already impaired by residual anaesthetic drugs; however, miners may be reluctant to report symptoms for fear of losing income; **Ee**, therefore, the strategy should continue but coupled with education on the risks of working underground while recovering from surgery or anaesthesia; **Ep**

Item 3

a) Blood oxygen saturation, tissue oxygenation and headache and weakness

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Blood oxygen saturation was lower in Kyambade than in Pius; **AI**, due to poor ventilation in the shelter and the use of charcoal stoves for warmth; **Ae**, which produced carbon monoxide that accumulated in the enclosed space. Carbon monoxide binds to haemoglobin with a much higher affinity than oxygen, forming carboxyhaemoglobin and reducing the haemoglobin available to carry oxygen. This reduced the oxygen saturation of the blood and the delivery of oxygen to the tissues, including the brain and skeletal muscles; the reduced oxygen supply to the brain caused a severe headache, while the reduced oxygen supply to the muscles reduced aerobic respiration and ATP production, causing weakness; **Ap**

ADH activity, water conservation and signs of dehydration

ADH activity was higher in Kyambade than in Pius; **AI**, due to limited access to drinking water during the night in the poorly ventilated shelter; **Ae**, the reduced water intake increased the osmotic pressure of the blood, which was detected by osmoreceptors in the hypothalamus, stimulating increased secretion of ADH from the posterior pituitary gland; ADH increased the permeability to water of the walls of the distal convoluted tubule and collecting duct, enhancing water reabsorption and reducing water loss in urine; however, this only conserved the limited water already in the body and could not replace the water that was lacking, so the body remained dehydrated which resulted in Kyambade showing signs of dehydration; **Ap**

Core body temperature, enzyme activity and slow withdrawal of the legs

Core body temperature was lower in Kyambade than in Pius; **AI**, it is attributed to the cold highland conditions in Kabale and the poorly ventilated shelter; **Ae**, this caused excessive heat loss from Kyambade's body by conduction and convection, which reduced the rate of enzyme-controlled metabolic reactions in the nervous system and muscles, slowing down the transmission of nerve impulses and the contraction of muscles, which resulted in Kyambade showing slow withdrawal of the legs from a sharp rock; **Ap**

The reduction in core body temperature reduced enzyme activity, reducing the rate of enzyme-controlled reactions like respiration hence a lower ATP production, which is required for muscle contraction, nerve impulse transmission, and cellular repair; the reduced ATP supply caused weakness and a higher reaction time to stimulus, which resulted in Kyambade experiencing weakness and slow withdrawal of the legs from a sharp rock; **Ap**

b) Improve ventilation of the shelters

It is effective; **EI**, improving ventilation of the shelters reduces the accumulation of carbon monoxide produced by charcoal stoves, lowering the formation of carboxyhaemoglobin and restoring blood oxygen saturation; this improves oxygen delivery to the brain and muscles, supporting aerobic respiration, ATP production, physical performance and faster reaction times; however, improving ventilation may reduce the warming effect of the charcoal stoves, making the shelter colder; **Ee**, therefore, the strategy should continue but coupled with the use of safer heating alternatives and carbon monoxide detectors; **Ep**

Provide adequate drinking water and planned hydration

It is effective; **EI**, providing adequate drinking water and planned hydration reduces the osmotic pressure of the blood, lowering ADH activity and preventing dehydration; with adequate water intake, the body can maintain normal blood volume and osmotic pressure, supporting proper cell function, nerve impulse transmission and muscular coordination; however, coldness may limit the water intake since tourists may not drink enough water if they do not feel thirsty; **Ee**, therefore, the strategy should continue but coupled with education on the importance of regular hydration in cold conditions; **Ep**

Provide suitable warm clothing and insulated shelter

It is effective; **EI**, providing suitable warm clothing and insulated shelter reduces heat loss from the body by trapping a layer of still air as insulation and reducing heat loss by conduction and convection; this helps maintain a core body temperature closer to the normal range, supporting enzyme activity, nerve impulse transmission, muscular coordination and cellular ATP production; however, warm clothing can become damp from sweat or condensation, which reduces its insulating properties; **Ee**, therefore, the strategy should continue but with waterproof and moisture-wicking insulated clothing; **Ep**

Item 4

a) Respiratory rate, oxygen intake and oxyhaemoglobin percentage

Respiratory rate was higher immediately after the whistle was sounded than in the resting state; **AI**, it is attributed to the elephants associating the electronic whistle with the start of an active work session; **Ae**, this is because the sound was collected and channeled to their inner ear where the sound energy was converted to mechanical energy and then an impulse was formed that was taken to the brain for interpretation, indicating the start of work; this triggered the sympathetic nervous system, which stimulated the adrenal medulla to release adrenaline. Adrenaline circulated in the blood and stimulated the respiratory centre in the medulla oblongata to increase the rate and depth of breathing; the rapid breathing increased the intake of oxygen into the lungs, so more oxygen diffused into the blood and

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combined with haemoglobin, raising the percentage of oxyhaemoglobin to supply the oxygen needed in respiration to produce energy for the activity, which resulted in the elephants flapping their ears vigorously for thermoregulation and salivating excessively as part of the stress response.

The increased respiratory rate caused excessive production of carbon dioxide and its elimination from the lungs; since carbon dioxide dissolves in blood to form carbonic acid, the removal of too much carbon dioxide reduced the concentration of carbonic acid in the blood, causing respiratory alkalosis; the rise in blood pH above the normal range impaired enzyme activity and neuromuscular function, contributing to marked muscle weakness; **Ap**

The rapid breathing triggered by the sympathetic nervous system and the hot afternoon conditions increased heat absorption by the elephants from the air by radiation and conduction, making the elephants flap their ears vigorously to increase heat loss by convection and evaporation, but this response also required energy and increased blood flow to the ears, elevating core body temperature, reducing enzyme activity, increasing metabolic stress, and diverting energy away from muscular work, contributing to exhaustion, which resulted in several elephants collapsing from exhaustion; **Ap**

b) Completely stop using the electronic whistle and use a silent, visual hand signal to train the elephants

It is effective; **EI**, this removes the conditioned stimulus that triggers the strong sympathetic nervous system response, preventing the sudden release of adrenaline, the rapid increase in respiratory rate, the rise in blood pH and the excessive salivation and ear flapping; this reduces the risk of exhaustion and collapse during work sessions; however, elephants may need to be retrained to respond to the new silent visual hand signal and the new signal less effectiveness over long distances or in poor visibility; **Ee**, therefore, the strategy should continue but coupled with gradual retraining of the elephants and use of consistent visual signals; **Ep**

Provide regular exercise for the elephants to improve cardiovascular fitness

It is effective; **EI**, regular exercise improves cardiovascular fitness by strengthening the heart muscle, increasing stroke volume and cardiac output, improving blood supply to the muscles and increasing the number and size of mitochondria in muscle cells; this allows the elephants to carry out physical work with less reliance on anaerobic respiration, reducing the accumulation of lactic acid and the risk of exhaustion; however, this increases the effects during hot afternoons, when the elephants are already at risk of heat stress; **Ee**, therefore,

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the strategy should continue but with exercise scheduled during the cooler early morning hours; **Ep**

Mix large amounts of citric acid into the elephants' drinking water

It is effective; **EI**, mixing citric acid into drinking water lowers blood pH and help correct respiratory alkalosis, since the rapid breathing after the whistle caused excessive elimination of carbon dioxide and a rise in blood pH; however, citric acid is a weak acid and its effect on blood pH is limited because the body has powerful buffering systems (bicarbonate, phosphate and protein buffers) that resist changes in pH and adding large amounts of citric acid to drinking water may also make the water unpalatable, reducing water intake and worsening dehydration; **Ee**, therefore, it should be done but with moderate amounts and combined with other little amounts of a relatively stronger acid; **Ep**

Item 6

a) Blood water potential, dehydration and body mass loss

Blood water potential was lower in the heat-stressed worker than in the normally hydrated worker; **AI**, it is attributed to the worker drinking very little water during the working period; **Ae**, working for more than four hours continuously in direct afternoon sunlight with high environmental temperatures led to increased heat gain by the body through radiation and conduction increasing the blood temperature which was detected by the thermal receptors, impulse sent to the thermoregulatory center and correction measures initiated which caused excessive sweating as the body attempted to lose heat by evaporation; the water lost through sweating was not replaced by drinking, so the water content of the blood decreased and the concentration of solutes in the blood increased lowering the blood water potential compared to the normally hydrated worker. This therefore disrupted the transportation of nutrients to the body and brain cells, which resulted in the heat-stressed worker becoming confused and weak and unable to maintain his usual working pace; **Ap**

The low blood water potential caused by water loss through sweating that was not replaced by drinking lowered blood water potential which was detected by osmoreceptors in the hypothalamus, which stimulated the posterior pituitary gland to secrete more ADH; ADH increased the permeability to water of the walls of the distal convoluted tubule and collecting duct, so more water was reabsorbed into the blood and a smaller volume of more concentrated urine was produced; however, this only conserved the limited water already in the body and could not replace the water that was lost, so the cellular activities were continuously affected and body mass continued to fall which resulted in a higher body mass loss in the heat-stressed worker compared to the normally hydrated worker; **Ap**

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The reduced blood water volume caused by dehydration and the increased demand for blood flow to the skin for heat loss and to the muscles for physical work lowered stroke volume, so the heart had to beat faster to maintain cardiac output and blood pressure; the increased heart rate also increased the workload on the heart and diverted blood away from the brain; the reduced blood supply to the brain reduced the supply of oxygen, glucose, and other nutrients, which affected the cell activities, making the heat-stressed worker confused and weak and unable to maintain his usual working pace with higher reaction time due to poor coordination; **Ap**

b) Taking regular water breaks

It is effective; **EI**, drinking water at regular intervals replaces the water lost through sweating, maintaining blood water potential within the normal range and preventing dehydration; with adequate water intake, blood volume is maintained, stroke volume and cardiac output remain normal, maintaining adequate blood supply to the brain and muscles, which improves reaction time and physical performance; however, workers may be reluctant to take water breaks because the construction schedule requires continuous progress; **Ee**, therefore, the strategy should continue but coupled with provision of more drinking-water points closer to the work areas and education on the importance of regular hydration; **Ep**

Resting in shaded areas

It is effective; **EI**, shade reduces exposure to direct solar radiation, lowering the amount of heat absorbed by the body by radiation and reducing the need for evaporative cooling through sweating; this reduces water loss, helps maintain blood water potential and blood volume, lowering the risk of dehydration and heat stress; however, shade position and size change with the time of day and may become crowded, leading to competition and reduced rest quality; **Ee**, therefore, the strategy should continue but with provision of adequate shaded rest areas, scheduled rest periods during the hottest part of the day, and rotation of workers to ensure everyone has access to shade; **Ep**

Avoiding prolonged strenuous work during the hottest periods

It is effective; **EI**, it reduces the duration of exposure to high environmental temperatures and direct sunlight, lowering heat gain by radiation and conduction and reducing the need for excessive sweating; this helps maintain blood water potential, blood volume and core body temperature within normal ranges, supporting normal enzyme activity, nervous coordination and muscular function; however, reducing work during the hottest periods lowers productivity and may delay the construction schedule; **Ee**, therefore, the strategy

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should continue but with adjustment of the construction schedule to shift strenuous work to the cooler early morning and late afternoon hours and rotation of workers during hot periods to reduce heat gain: **Ep**

Item 8

a) Rhodopsin recovery time, photoreceptor adaptation and temporary blindness

Rhodopsin recovery time after bright light was longer in the affected guard than in the healthy colleague; **AI**, due to the guard being suddenly exposed to a bright security floodlight after hours of darkness; **Ae**, in darkness, rhodopsin (visual purple) accumulates in the rod cells, increasing their sensitivity to dim light; when the guard was suddenly exposed to bright light, the rhodopsin was rapidly bleached into opsin and retinal, so the rod cells could not respond to light, causing temporary blindness; the rhodopsin then had to be resynthesised in the dark which required a time making the guard temporarily blind and excessive tearing during the reaction to the sudden light; **Ap**

Synaptic transmission efficiency, neuromuscular coordination and response to the dog scratch

Synaptic transmission efficiency at the neuromuscular junction was lower in the affected guard than in the healthy colleague; **AI**, due to the prolonged exposure to coldness at night; **Ae**, synaptic transmission at the neuromuscular junction depends on the release of acetylcholine from the presynaptic neuron and its diffusion across the synaptic cleft requires a normal body temperature to increase the kinetic energy of the diffusing particles, this therefore slowed their movement and together with the slowed movement of ions into the postsynaptic knob slowed depolarization and development of the excitatory post synaptic potential which contributed to the guard's delayed responses and reduced ability to react quickly to the dog scratch; **Ap**

Blood histamine concentration, inflammatory response and redness, swelling and warmth

Blood histamine concentration was lower in the affected guard than in the healthy colleague; **AI**, due to the scratch from the dog; **Ae**, when the guard was scratched by the stray dog, the damaged tissue cells and mast cells released histamine at the wound site; histamine causes vasodilation of arterioles and increases the permeability of capillaries, so more blood flows to the wound area and plasma proteins and fluid leak into the surrounding tissues.

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This caused the redness, swelling and warmth observed at the wound site; however, because the guard's blood histamine concentration was lower than normal, the inflammatory response may have been less effective, delaying the arrival of immune cells and slowing wound healing, which resulted in the wound area becoming red, swollen and warm within minutes; **Ap**

Blood oxygen saturation, tissue oxygenation and the guard's overall condition

Blood oxygen saturation was lower in the affected guard than in the healthy colleague; **Al**, due to the guard being a heavy smoker; **Ae**, carbon monoxide in cigarette smoke binds to haemoglobin with a much higher affinity than oxygen, forming carboxyhaemoglobin, reducing the amount of haemoglobin available to carry oxygen, so less oxygen was delivered to the tissues. The anaemia, which reduces the number of red blood cells and the amount of haemoglobin, further reduced the oxygen-carrying capacity of the blood; the low blood oxygen saturation reduced aerobic respiration and ATP production in the rod cells of the retina, slowing rhodopsin resynthesis, in the nerve and muscle cells, slowing synaptic transmission and in the immune cells, slowing wound healing, which resulted in the guard experiencing prolonged rhodopsin recovery time, reduced synaptic transmission efficiency, and slow wound healing; **Ap**

b) Improve site lighting to prevent sudden glare exposure

It is effective; **El**, it reduces the contrast between the darkness of the night and the sudden brightness of the security floodlight, reducing the sudden bleaching of rhodopsin in the rod cells, preventing painful glare and temporary blindness; however, poorly designed and installed lighting may still create glare or leave dark areas; **Ee**, therefore, the strategy should continue but with motion-activated or gradually brightening lights; **Ep**

Use of antihistamines

It is effective; **El**, these reduce vasodilation and capillary permeability at the wound site, which reduces the redness, swelling and warmth caused by the dog scratch; however, antihistamines may cause drowsiness, which is dangerous for a security guard on night duty; **Ee**, therefore, antihistamines should be used but with non-sedating types preferred for night-duty guards; **Ep**

Train guards in animal-hazard awareness and first-aid wound care

It is effective; **El**, it enables them to recognise the risks posed by stray animals, avoid contact where possible, and respond quickly and correctly if scratched or bitten while proper first-aid wound care, including washing the wound, applying antiseptic and seeking medical attention, reduces the risk of infection, including rabies and tetanus, and promotes faster

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healing; however, if the training of wound care isn't understood well, it was induce advace effects if the first aid care chemicals aren't use well; **Ee**, therefore, the strategy should continue but coupled with provision of first-aid kits at the site and regular refresher training; **Ep**

Item 10

a) Core body temperature, skin superficial arteriole diameter and pale skin

Core body temperature was lower in Peter than the reference point; **AI**, due to immersion and prolonged exposure to the cold deep seawater, caused rapid heat loss from his body by conduction and convection; **Ae**, the low temperature in the seawater created a steep thermal gradient between his body and the surrounding environment, which increased heat loss from Peter's body by conduction and convection, reducing the skin and the core body temperature. The cold thermoreceptors of the skin and the deep thermal receptors of core organs fired impulses to the heat gain center of the hypothalamus, which sent impulses to the superficial arterioles, causing vasoconstriction, which greatly reduced blood flow through superficial capillaries to minimize heat loss to the cold environment; however, prolonged vasoconstriction reduced oxygen delivery to the skin and fingers, so haemoglobin in the capillary blood became increasingly deoxygenated, which resulted in the observed pale skin; **Ap**

Blood volume, cardiac output and low blood pressure

Blood volume was lower in Peter than the reference point; **AI**, due to the bleeding from the leg wound caused by the sea creature attack; **Ae**, the loss of blood reduced the volume of blood in the circulation, which lowered venous return, stroke volume and cardiac output. resulting in minimal stretching of the walls of the aorta and carotid arteries, hence low blood pressure; **Ap**

Sympathetic:parasympathetic nerve activation by baroreceptors, blood pressure and heart rate

Sympathetic:parasympathetic nerve activation by baroreceptors was higher in Peter than the moderate reference point; **AI**, due to the fall in blood pressure caused by the blood loss from sea creature attack; **Ae**, this resulted in lower cardiac output causing minimal stretching of the walls of the aorta and carotid arteries, whose baroreceptors sent very few impulses to the cardiac inhibitory center in the medulla oblongata; the cardiovascular centre increased sympathetic stimulation and reduced parasympathetic stimulation to the SAN, increasing its depolarization to produce more waves of excitation, hence increasing his heart rate; **Ap**

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Generator region membrane potential of nociceptors in the leg and pain

The generator region membrane potential of nociceptors in the leg was higher in Peter than the reference point; **AI**, attributed to the tissue damage caused by the sea creature attack; **Ae**, the tissue damage increased prostaglandin release and also presented a stimulus with larger magnitude, making very many sodium channels open; many sodium ions entered, which depolarised the inside of nociceptor membranes, forming a larger generator potential and impulses were discharged from nociceptors at shorter intervals hence having a lot of pain; **Ap**

b) Hypotonic warm fluids

It is effective; **EI**, the warm fluid raises his core body temperature after absorbing the heat, and the increase is detected by the heat-gain center in the hypothalamus, which fires impulses to superficial arterioles, causing vasodilation, restoring blood flow to the skin, relieving paleness and the fluids are absorbed rapidly from the gut into the blood, increasing blood volume and raising blood pressure; however, excessive consumption of hypotonic fluids can greatly lower blood's osmotic pressure and damage body cells; **Ee**, therefore, the strategy should continue but coupled with blood transfusion and administration of regulated volumes; **Ep**

Pain relievers

It is effective; **EI**, they block pain signals from the nociceptors to the brain ie some inhibit enzymes required for prostaglandin formation, reducing nociceptor depolarisation, which lowers awareness of pain; however, pain relievers may mask the severity of the injury and delay immune and inflammatory responses of the body due to suppression of prostaglandin release, delaying wound healing; **Ee**, therefore, the strategy should continue but administered in appropriate dose with careful wound assessment; **Ep**

Antidiuretics

It is effective; **EI**, they increase water reabsorption in the distal convoluted tubule and collecting duct, reducing water loss in urine, restoring blood volume and blood pressure; however, excessive antidiuretic administration lowers blood osmotic pressure and electrolytes, which interfere with normal cell functioning; **Ee**, therefore, the strategy should continue but coupled with blood transfusion and careful monitoring of blood pressure and urine output; **Ep**

Item 11

a) Blood oxygen-carrying capacity, and general body weakness

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Blood oxygen-carrying capacity was lower in Mkuju residents than in the non-resident; **AI**, due to inhalation of tobacco and cigarette smoke within the cold mines; **Ae**, carbon monoxide in tobacco and cigarette smoke binds to haemoglobin, forming a relatively stable carboxyhaemoglobin, reducing the amount of haemoglobin available to carry oxygen; few oxyhaemoglobin formed, less oxygen delivered to the tissues, aerobic respiration and ATP production decline; which resulted in general body weakness; **Ap**

Status of respiratory tract, and breathing difficulties

The respiratory tract of Mkuju residents had fewer cilia and blocked airways compared to the non-resident; **AI**, it is attributed to the residents inhaling tobacco and cigarette smoke and working in the mines without special suits, exposing them to uranium dust and other particulates; **Ae**, the smoke contained tar which paralysed most cilia and mine dust damaged the ciliated epithelial cells lining the airways, also radon gas from radioactive decay of uranium further damaged lung tissue; so fewer cilia remain to sweep mucus and trapped particles out of the respiratory tract; the accumulation of mucus and particles blocks the airways; this reduces the passage for air flow, increased the resistance to airflow; which resulted in breathing difficulties; **Ap**

Organ damage index, duodenal blockage and kidney problems

Organ damage index was higher in Mkuju residents than in the non-resident; **AI**, it is attributed to prolonged exposure to uranium mining waste, and uranium mine environment without special suits; **Ae**, radioactive substances such as uranium emit ionising radiation that damages DNA, which impairs the normal cell cycle, causing kidney problems; **Ap**

Angiogenic growth factors, and cancerous duodenal blockage

Angiogenic growth factors were higher in Mkuju residents than in the non-residents; **AI**, it is attributed to the cancerous tumours that developed in the residents' duodenum as a result of prolonged exposure to uranium mining waste; **Ae**, uranium caused alteration in proto-oncogenes to oncogenes and modification of the tumour suppressor genes. This results in the production of proteins in the cells of the duodenum that cause uncontrolled division, forming cancerous tumours, and those in the middle of the tumours release angiogenic growth factors to stimulate the formation of new blood vessels to supply the growing tumour with oxygen and nutrients, for the tumour to grow larger and to block the duodenum, causing the blockage observed; **Ap**

b) Installation of an effluent treatment plant

It is effective; **EI**, it removes radioactive substances, heavy metals and other toxic chemicals from the uranium plant's waste before it is discharged into the Mkuju water source; this

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reduces the residents' exposure to carcinogens and organ-damaging substances, lowering the risk of cancerous tumours and kidney problems; however, effluent treatment plants require regular monitoring of effluent quality and trained personnel; **Ee**, therefore, the strategy should continue but coupled with a computerized system to monitor effluent quality; **Ep**

Providing personal protective equipment to the workers

It is effective; **EI**, it reduces their exposure to uranium dust, radioactive particles and other harmful substances in the mines; this reduces damage to the respiratory tract, lowers the organ damage index and reduces the risk of cancerous tumours; however, PPE is only effective if worn correctly and consistently, and it may be uncomfortable or inconvenient for workers, leading to poor compliance; **Ee**, therefore, the strategy should continue but with regular training on the correct use of PPE, supervision to ensure compliance; **Ep**

Genetic testing of the workers

It is effective; **EI**, it can identify individuals with mutations in proto-oncogenes and tumour suppressor genes, which increases the possibility of detecting the likelihood of cancer before the development of a tumour; however, it causes anxiety and faces low compliance by the workers; Ee, therefore, the strategy should continue but with better sensitization and genetic counselling; **Ep**

Change in lifestyle and diet of workers

It is effective; **EI**, stopping smoking reduces exposure to carbon monoxide and carcinogens, improving blood oxygen-carrying capacity and reducing damage to the respiratory tract; a balanced diet rich in antioxidants, vitamins and minerals supports the immune system, and reduces the risk of cancerous tumours; however, lifestyle change requires education, motivation and support, and it may be difficult for workers who smoke to keep warm in the cold mines; **Ee**, therefore, the strategy should continue but with counselling sessions and provision of warm clothing and heating in the mines to remove the need to smoke; **Ep**

ASSESSMENT OBJECTIVE 4: GENETIC, EVOLUTIONARY, AND ECOLOGICAL DYNAMICS

Item 1

a) Initial susceptibility of the stem borer population and success of the programme

Initially, the stem borer population consisted of insecticide-susceptible individuals; **AI**, because IRRI-8 rice had just been introduced and the pyrethroid insecticide had not been used before; **Ae**, the pyrethroid insecticide was toxic to susceptible stem borer larvae and resulted in their eventual death, so stem borer populations were initially reduced, and farmers recorded very little damage from stem borers during the first three growing

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seasons, leading to high rice yields, which resulted in the initial success of the programme; **Ap**

Evolution of insecticide resistance through natural selection

After five seasons of continuous insecticide use, the stem borer population consisted of two distinct groups those that were susceptible to the insecticide and were killed, and those that survived exposure and reproduced successfully on the treated rice; **AI**, this was due to the evolution of insecticide-resistant stem borers through natural selection; **Ae**, after widespread and repeated application of the pyrethroid insecticide, the stem borer population developed genetic variation arising from spontaneous mutations; a few individuals acquired alleles that conferred resistance to the insecticide, while the majority were susceptible; continuous spraying acted as a strong selection pressure and susceptible stem borers died when exposed to the insecticide and failed to pass on their genes to their offspring, hence their numbers decreased, whereas resistant individuals survived, completed their life cycle and produced offspring carrying the resistance alleles. Over successive generations, the frequency of resistant alleles increased, resulting in a large resistant population capable of feeding and reproducing on the treated rice, hence pest resurgence; **Ap**

Gene flow and spread of resistance between districts

There is increased gene flow between neighbouring stem borer populations; **AI**, due to migration of adult stem borers during the wet season; **Ae**, as a result of interbreeding, resistant individuals introduced resistance alleles into neighbouring populations, while susceptible individuals from unsprayed rice fields entered sprayed areas; this movement altered allele frequencies across districts and accelerated the spread of insecticide resistance; **Ap**

Decline of natural enemies and increase in planthopper infestations

Populations of spiders and dragonflies declined considerably in the affected field after five seasons of continuous insecticide use; **AI**, due to the widespread use of the pyrethroid insecticide; **Ae**, broad-spectrum insecticides killed beneficial organisms including spiders and dragonflies, which are natural predators of rice pests; as these natural enemies died, there was a decrease in the amount of predation on planthoppers which lowered the mortality of planthoppers, allowing more individuals to grow and reach the reproductive stage; more offspring were produced, increasing their population over the years which lowered food security; **Ap**

Role of flowering bunds and crop rotation in mitigating ecological changes

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There was a reduced change in the allele frequencies in neighbouring fields where farmers maintained flowering plants along the bunds and practised crop rotation between rice and legumes; **Al**, due to the presence of flowering plants and crop rotation; **Ae**, flowering plants along the bunds provided nectar and pollen for adult spiders and dragonflies, and alternative habitats and prey for natural enemies, so their populations were maintained and continued to suppress planthopper populations. Crop rotation between rice and legumes also interrupted the life cycle of the stem borer by reducing the continuous availability of its preferred host plant, which resulted in a lower frequency of the insecticide-resistant allele, hence higher food security; **Ap**

b) Routine use of broad-spectrum insecticides at higher concentrations

It is effective; **EI**, these rapidly reduce populations of both susceptible and resistant stem borers, providing immediate protection of rice crops, and may also suppress secondary pests such as planthoppers in the short term; however, they kill beneficial organisms including spiders and dragonflies, which provide ecological services such as natural pest control, and residues result in environmental pollution. Higher concentrations create even stronger selection pressure for insecticide-resistant stem borer populations, and repeated use will accelerate the evolution of resistance, making the problem worse in the long term; **Ee**, therefore, routine broad-spectrum spraying at higher concentrations should be done only when pest populations exceed economic threshold levels and integrated with other pest control strategies such as crop rotation and conservation of natural enemies; **Ep**

Introduction of a new genetically modified rice variety carrying a different insecticidal gene

It is effective; **EI**, this effectively kills stem borers that have developed resistance to the pyrethroid insecticide, increasing crop yields rapidly while reducing dependence on conventional insecticides; however, continuous use of the new genetically modified variety may eventually select for resistance to the new toxin, and may also pose ecological effects on non-target organisms; **Ee**, therefore, the new genetically modified rice variety should be introduced together with resistance-management strategies such as refuge and with regular monitoring of stem borer populations for signs of resistance; **Ep**

Maintenance of the original rice variety but alternating it with legumes and flowering bund plants

It is effective; **EI**, crop rotation interrupts the life cycle of the stem borer by reducing the continuous availability of its preferred host plant while maintaining flowering plants along the bunds provides nectar and pollen for adult spiders and dragonflies, and alternative

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habitats and prey for natural enemies, so their populations are maintained and continue to suppress stem borer and planthopper populations; however, some stem borers may survive on alternative host plants or migrate from neighbouring farms; **Ee**, therefore, this should be implemented, but with critical monitoring of the pest population, farmer training and coordinated area-wide pest management; **Ep**

Item 2

a) Allele frequency, population evolution and environmental stability

From year 0 to year 20, the allele frequency of the dominant allele G (green body colour) increased, whereas the allele frequency of the recessive allele g (brown body colour) decreased; **Al**, due to the change and increase in complexity of the dominant vegetation cover during rangeland recovery; **Ae**, initially, the green forms were selected against because they could not camouflage well in the sparse grasses and bare patches, making them easier to see and be fed on by predatory birds, causing a reduction in the number of reproductive individuals; hence, few passed on their genes to the next generation compared to those with the recessive allele g; however, when the vegetation became denser and greener because of increasing grass, shrub and tree cover and shaded conditions, green grasshoppers blended more effectively with the green vegetation and escaped predation from visually hunting birds compared to the brown grasshoppers; the green grasshoppers were therefore selected for, which increased their chances of surviving to reproductive age and producing more offspring with the G allele. Over successive generations, the frequency of the G allele increased while the frequency of the g allele decreased, demonstrating evolution through changes in allele frequencies within the population as a result of directional selection, which resulted in a higher frequency of allele G in the late recovery stage compared to the early recovery stage; **Ap**

Relative humidity, transpiration and microclimate modification

From year 0 to year 20 post-clearing, relative humidity increased; **Al**, due to increasing vegetation cover during succession; **Ae**, as vegetation cover increased, transpiration from leaves released large quantities of water vapour into the atmosphere, and the developing canopy reduced direct solar radiation reaching the soil surface, lowering evaporation rates and maintaining higher atmospheric moisture, which resulted in a cooler and more humid local climate in the surrounding environment after 20 years; **Ap**

Soil carbon sequestration, photosynthesis and carbon footprint

From year 0 to year 20 post-clearing, soil carbon sequestration increased; **Al**, due to increasing complexity in vegetation cover; **Ae**, increased vegetation cover complexity

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increased carbon dioxide uptake from the atmosphere for use in photosynthesis; this led to the formation of organic matter, and therefore large amounts of carbon became stored within trunks, branches, roots, leaf litter and soil organic matter, which resulted in a reduced carbon footprint of the surrounding environment; **Ap**

Dominant vegetation during succession

From year 0 to year 2 post-clearing, sparse grasses and bare patches dominated the vegetation; **Al**, due to the harsh conditions on the bare, degraded, and compacted ground; **Ae**, these pioneer species were able to colonise the exposed ground because they tolerate harsh environmental conditions like high temperatures and low moisture. Their roots stabilised the soil and added organic matter to the soil through decomposition, improving soil fertility.

From year 2 to year 10 post-clearing, dense grasses and shrubs became the dominant vegetation; **Al,** as a result of the increased soil depth and moisture from the death and decomposition of the pioneer grasses; **Ae**, the increased soil depth, organic matter, and nutrients were suitable for the growth of larger plants and shrubs, therefore replacing the sparse grasses and also producing greater biomass and shade, further modifying the environment and facilitating succession.

From year 10 to year 20 post-clearing, open woodland and young trees had become dominant; **Al,** because of the increased soil depth important for tree root anchorage; **Ae** this supported tree growth, and these being taller, outcompeted shrubs for sunlight. The developing woodland canopy created a more stable ecosystem with increased structural complexity and biodiversity; **Ap**

b) Immediate planting of mature, exotic pine trees to maximise carbon sequestration

It is effective; **El**, pine trees grow rapidly and produce large amounts of biomass, enabling rapid carbon sequestration, and rapid canopy formation quickly shades the ground, increasing the relative humidity, which increases the rate of decomposition, hence faster recovery of the ecosystem; however, pine trees have a very high water demand, which may lower soil moisture, and many native insects, birds and other animals are poorly adapted to pine plantations, reducing native biodiversity; **Ee**, therefore, planting extensive stands of mature pine should only be adopted in association with other tree species with fast growth and low water demand, and with indigenous species to maintain biodiversity; **Ep**

Assisted natural regeneration of native grass and tree species

It is effective; **El**, this allows the existing soil seed bank and remnant vegetation to recover naturally and maintain native species, preserving the genetic diversity and ecological

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interactions of the original rangeland; it also supports the native grasshopper population and the predatory birds that feed on them, maintaining the evolutionary balance; however, natural regeneration may be slow and vulnerable to disturbance such as fire, grazing and further land degradation; **Ee**, therefore, this strategy should be implemented alongside protection measures such as fencing, community patrols and controlled access; **Ep**

Controlled grazing and seasonal burning to manage vegetation structure

It is effective; **EI**, controlled grazing allows vegetation to recover between grazing periods, and seasonal burning removes dead plant material, recycles nutrients and promotes new growth, maintaining the structure and productivity of the rangeland; however, if poorly managed, controlled grazing and burning can still damage vegetation and cause death to some beneficial organisms; **Ee**, therefore, this strategy should be implemented with clear grazing plans, burning schedules based on ecological principles, and regular monitoring of vegetation and soil condition; **Ep**

Community-based seed banks and nurseries for native tree species

It is effective; **EI**, these conserve locally adapted native tree and grass species, improve the availability of planting material for restoration, and reduce dependence on exotic species; however, seed banks require proper storage facilities, and seeds can lose viability over time if stored poorly; **Ee**, therefore, this strategy should be implemented with training on seed storage and regular testing of seed viability; **Ep**

Establishment of forest corridors to reconnect isolated patches of vegetation

It is effective; **EI**, they reconnect isolated patches of vegetation, allowing gene flow between populations of native plants and animals, including the grasshoppers and their predators; this increases genetic diversity, reduces the effects of habitat fragmentation and supports the recovery of the ecosystem; however, forest corridors require land and long-term protection which may conflict with grazing and other land uses; **Ee**, therefore, this strategy should be implemented with community engagement, clear boundary demarcation and regular monitoring; **Ep**

Item 3

a) Linkage and changes in bollworm population

The two parental phenotypes high feeding rate with insecticide resistance and low feeding rate with insecticide susceptibility were higher in the offspring than the recombinant phenotypes of high feeding rate with insecticide susceptibility and low feeding rate with insecticide resistance; **AI**, this is because the two genes, for feeding rate (F) and insecticide resistance (R), occur on the same chromosome; **Ae**, these genes are partially linked and tend

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to be inherited together rather than assorting independently; therefore, formation of recombinants occurs by crossing over, which happens by chance; this increases the frequency of occurrence of the parental phenotypes compared to the recombinants in the bollworm population which resulted in a higher proportion of bollworms possessing both high feeding rate and insecticide resistance in the affected field; **Ap**

Crossing over and changes in bollworm population

The recombinant groups high feeding rate with insecticide susceptibility and low feeding rate with insecticide resistance were fewer than the offspring with parental phenotypes; **AI**, because recombinants are formed by crossing over; **Ae**, giving 145 recombinants out of 950 offspring, which is about 15.3% recombination and corresponds to the 11% crossing over frequency reported in the table; this shows that the genes are relatively far apart and therefore partially linked which offers a chance for crossing over to happen, leading to the formation of recombinants, though these are formed in fewer numbers since crossing over happens by chance hence the lower proportion of bollworms with recombinant phenotypes in the affected field; **Ap**

Insecticide selection pressure and changes in bollworm population

The bollworms possessing both high feeding rate and insecticide resistance were higher than the bollworms with low feeding rate and insecticide resistance; **AI**, this is because repeated spraying with lambda-cyhalothrin provided a selection pressure selecting against the susceptible bollworms and favouring bollworms with the resistance allele R; **Ae**, the susceptible bollworms were therefore killed, leaving fewer reproducing individuals, whereas resistant bollworms survived and contributed more offspring to the next generation; since high feeding rate is linked to resistance, the frequency of the combined traits increased, allowing the population to become more damaging to cotton; **Ap**

Food security and changes in bollworm population

The bollworms possessing both high feeding rate and insecticide resistance were higher than the bollworms with low feeding rate and insecticide resistance, which caused greater crop damage and reduced cotton production; **AI**, this is because their resistance confers a selective advantage to survive insecticide treatment; **Ae**, while their high feeding rate allows them to consume more cotton tissue; surviving resistant and high-feeding bollworms continue feeding and reproducing after repeated insecticide application, and their increased abundance increases pest pressure, resulting in greater crop damage and lower cotton yield; the declining yields reduced household income, while rising cotton prices reduced

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access to food in the community hence the lower household food access in the affected field compared to the healthy field; **Ap**

b) Integrated pest management (IPM); combining biological, cultural and chemical control

It is effective; **EI**, this reduces the selection pressure from repeated use of one insecticide, slowing the evolution of resistance, helping to reduce bollworm populations and improve cotton productivity and food security; however, IPM requires knowledge, regular monitoring and coordinated implementation, and poorly managed insecticide use within an IPM programme can still select for resistant pests; **Ee**, therefore, IPM should be maintained with regular pest monitoring and economic thresholds and rotation of insecticide modes of action when chemicals are necessary; **Ep**

Community cotton seed banks; preserving diverse, locally adapted varieties

It is effective; **EI**, it improves the availability of planting material and can reduce dependence on a single cotton variety, which helps maintain genetic diversity, which is important for long-term resilience against pests and changing environmental conditions; however, the stored varieties may be susceptible to the bollworm and seeds can lose viability over time if stored poorly; **Ee**, therefore, seed banks should store diverse, locally adapted and pest-tolerant varieties and test their performance under local conditions over time; **Ep**

Biological control using natural predators; introducing or conserving natural enemies

It is effective; **EI**, biological control using natural predators removes pest insects without relying on the same chemical selection pressure produced by repeated insecticide use, which reduces pest abundance and crop damage, ensuring no pest resurgence; however, natural predators may be affected by insecticides, absence of habitats, unfavourable environmental conditions, and may have a lower feeding rate than the pest's rate of reproduction, reducing their effectiveness; **Ee**, therefore, the strategy should be maintained but with conservation of habitats that support natural enemies, reduced broad-spectrum insecticide use and monitoring of predator and pest populations; **Ep**

Item 5

a) Initial susceptibility of the groundnut leaf miner and success of carbamate spraying

Initially, the groundnut leaf miner population consisted mainly of susceptible individuals; **AI**, because the synthetic carbamate insecticide had not been used before in the groundnut fields near the forest edge; **Ae**, the carbamate insecticide was toxic to susceptible leaf miner

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larvae and resulted in their eventual death, so leaf miner populations were initially reduced and crop losses were minimised during the early seasons, leading to better groundnut yields; which resulted in the initial success of the spraying programme; **Ap**

Evolution of carbamate resistance through natural selection

After five seasons of continuous carbamate spraying, the frequency of the resistant genotype RR and Rr increased, while the susceptible genotype rr decreased; **AI**, this was due to the evolution of carbamate-resistant groundnut leaf miners through natural selection; **Ae**, the groundnut leaf miner population carried a gene with two alleles: R, which confers resistance, and r, which confers susceptibility; before regular spraying, the population contained genetic variation, with a few individuals possessing the R allele; continuous carbamate spraying acted as a strong selection pressure and susceptible individuals with the rr genotype died when exposed to the insecticide and failed to pass on their genes to their offspring, hence their numbers decreased, whereas resistant individuals with the RR and Rr genotypes survived, completed their life cycle and produced offspring carrying the R allele. Over successive generations, the frequency of the R allele increased, resulting in a large resistant population capable of feeding and reproducing on the sprayed groundnut plants, hence pest resurgence; **Ap**

Gene flow and spread of resistance between neighbouring fields

There is increased gene flow between neighbouring groundnut leaf miner populations; **AI**, due to migration of adult leaf miners between sprayed and unsprayed groundnut fields and nearby forest margins; **Ae**, as a result of interbreeding, resistant individuals introduced the R allele into neighbouring populations, while susceptible individuals from unsprayed fields entered sprayed areas; this movement altered allele frequencies across the landscape and accelerated the spread of carbamate resistance; which resulted in a higher frequency of the resistance allele in the groundnut leaf miner population around Kalinzu Central Forest Reserve; **Ap**

Decline of bees, butterflies and insect-eating birds and ecological imbalance

Populations of bees, butterflies and insect-eating birds declined markedly along the forest margins during the period of continuous carbamate spraying; **AI**, due to the widespread use of the synthetic carbamate insecticide; **Ae**, broad-spectrum carbamate insecticides killed beneficial organisms including bees and butterflies, which are important pollinators, and reduced the insect prey available to insect-eating birds; reduced food availability lowered the survival and reproductive success of the birds, leading to their decline; the loss of bees and butterflies also reduced pollination services for wild plants and crops, while the loss of

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insect-eating birds removed natural predators of the groundnut leaf miner and other pests; **Ap**

Biomagnification of insecticide residues along the food chain

The mean insecticide residue increased from 0.03 ppm in groundnut leaves and forest foliage to 1.62 ppm in herbivorous caterpillars, 19.40 ppm in predatory ground beetles and 268.30 ppm in insectivorous birds; **AI**, due to the repeated application of synthetic carbamate insecticides and the persistence of these chemicals in the environment; **Ae**, insecticides are fat-soluble and are not easily broken down or excreted by organisms; when herbivorous caterpillars eat sprayed foliage, they accumulate the insecticide in their bodies; when predatory ground beetles eat many caterpillars, they accumulate the insecticide from all their prey; when insectivorous birds eat many beetles, they accumulate even higher concentrations; this process of biomagnification along the food chain resulted in the highest insecticide concentration in the top predator, the insectivorous birds; which resulted in the decline of bees, butterflies and insect-eating birds and the disruption of the food chain along the forest margin; **Ap**

b) Continuing carbamate spraying but reducing the concentration and frequency of application

It is effective; **EI**, this slows the rate at which resistance evolves and reduce the amount of insecticide entering the food chain, while still providing some control of the groundnut leaf miner; however, even reduced concentrations and frequencies will continue to select for resistant individuals, since the resistant genotypes RR and Rr are already present at high frequencies; the treatment will continue to kill beneficial organisms such as bees, butterflies and insect-eating birds, and the insecticide will still biomagnify along the food chain, harming top predators; **Ee**, therefore, this strategy should be done but with more targeted and sustainable pest management approaches, combined with monitoring of resistance and beneficial insect populations; **Ep**

Introducing newer insecticides with different modes of action

It is effective; **EI**, this effectively kills groundnut leaf miners that have developed resistance to carbamate insecticides, providing immediate protection of groundnut crops and increasing yields; however, continuous use of any insecticide will eventually select for resistance to the new chemical, just as it did for carbamates; newer insecticides may also kill beneficial organisms such as bees, butterflies and insect-eating birds, and may biomagnify along the food chain, causing similar ecological damage; **Ee**, therefore, newer

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insecticides should only be used as part of an integrated pest management programme, with rotation of modes of action; **Ep**

Introducing insect-eating birds within the groundnut plantation

It is effective; **EI**, birds are natural predators of the groundnut leaf miner and other insect pests; they reduce pest abundance without relying on chemical selection pressure, so no pest resistance arises; however, insect-eating birds may be affected by insecticides, absence of suitable habitats, and may have a lower feeding rate than the pest's rate of reproduction; **Ee**, therefore, this strategy should be maintained but with conservation of habitats that support insect-eating birds, reduced broad-spectrum insecticide use and monitoring of bird and pest populations; **Ep**

Item 6

a) Decline in dissolved oxygen, cichlid population decline and ecological change

Dissolved oxygen levels were lower in the current population than in the historical population; **AI**, due to increasing agricultural activities around the lake, which altered the biological conditions of the aquatic ecosystem in Napak Bay; **Ae**, agricultural runoff containing fertilisers and organic matter entered the lake, causing eutrophication; the increased nutrients stimulated the growth of algae and aquatic plants; when these died, decomposing bacteria multiplied and consumed large amounts of dissolved oxygen through aerobic respiration, reducing the oxygen available to the cichlids. The low dissolved oxygen levels caused hypoxia, which weakened the cichlids, reduced their feeding, growth and reproductive success, and increased mortality, resulting in the total cichlid population declining by approximately 25%; **Ap**

Allele frequency of yellow-colour allele (Y) and black-colour allele (B), sexual selection and population change

The frequency of the yellow-colour allele (Y) and black-colour allele (B) was lower in the current population than in the historical population; **AI**, due to changes in the biological conditions of the aquatic ecosystem caused by agricultural activities; **Ae**, this altered the mating preferences of female cichlids since in the past, female cichlids showed a strong preference for mating with yellow-coloured and black-coloured males; this sexual selection gave yellow-coloured and black-coloured males a reproductive advantage, so they produced more offspring carrying the Y allele, increasing its frequency; however, as the environment changed, the water became turbid and the light conditions changed, so female cichlids could no longer easily distinguish yellow-coloured males and black-coloured males; the yellow-coloured males and and black-coloured males lost their reproductive advantage, so fewer of

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them mated to pass on Y and B allele to the next generation. Over successive generations, the frequency of the Y and B alleles decreased, resulting in the yellow-coloured and black-coloured cichlids becoming increasingly uncommon, with the grey-coloured hybrid cichlids becoming more common due to random mating; **Ap**

b) Reduce agricultural runoff into the lake by promoting buffer strips of vegetation along the shoreline

It is effective; **EI**, buffer strips of vegetation along the shoreline trap sediments, nutrients and agricultural chemicals before they enter the lake; this reduces eutrophication, lowers the growth of algae and aquatic plants, and reduces the oxygen demand from decomposing organic matter, so dissolved oxygen levels can recover; however, buffer strips take time to become established and effective; **Ee**, therefore, this strategy should be implemented with farmer training on sustainable agricultural practices, provision of incentives for establishing buffer strips, and regular monitoring of water quality to track improvements; **Ep**

Establish protected breeding zones where fishing is restricted during spawning seasons

It is effective; **EI**, it allows cichlids to spawn and reproduce without disturbance from fishing during the spawning season; this increases the number of eggs laid and the number of fry that survive to adulthood, helping to rebuild the cichlid population and restore the yellow-coloured and black-coloured species; however, restricting fishing enforcement may be difficult without community support and adequate patrols; **Ee**, therefore, this strategy should be implemented with community consultation, alternative livelihood options for affected fishers during the closed season and regular monitoring of breeding success; **Ep**

Restock the lake with native yellow-coloured and black-coloured cichlid species from certified hatcheries

It is effective; **EI**, this helps restore the historical species composition, increases genetic diversity and supports the recovery of the cichlid population; however, the restocked fish may not survive if the water quality and dissolved oxygen levels remain poor; **Ee**, therefore, this strategy should be implemented alongside improvements in water quality (such as reducing agricultural runoff), and regular monitoring of survival; **Ep**

Monitor water quality regularly to track changes in dissolved oxygen and nutrient levels

It is effective; **EI**, it provides early warning of changes in dissolved oxygen and nutrient levels, allowing conservation officers to detect problems such as eutrophication and hypoxia before they cause widespread damage; however, monitoring requires equipment, trained

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personnel, and long-term commitment; **Ee**, therefore, this strategy should be implemented with training of local personnel and regular sampling at multiple sites; **Ep**

Item 7

a) Dissolved oxygen, eutrophication and the decline in native tilapia populations

Dissolved oxygen was lower in the present day than 15 years ago; **AI**, due to intensified agricultural practices within the surrounding catchment, where farmers increasingly used nitrogen- and phosphorus-rich fertilisers and cleared vegetation along riverbanks; **Ae** runoff from these farms entered the bay, increasing the nitrate concentration these increased nutrients stimulated rapid algal growth and when the algae died, decomposing bacteria multiplied and consumed large amounts of dissolved oxygen through aerobic respiration, reducing the oxygen available to aquatic organisms; the low dissolved oxygen caused hypoxia, which weakened the native tilapia, reduced their feeding, growth and reproductive success, and increased mortality; which resulted in a substantial decline in native tilapia populations and a lower water transparency compared to 15 years ago; **Ap**

Water transparency, light penetration and changes in tilapia colour forms

Water transparency was lower in the present day than 15 years ago; **AI**, due to the frequent algal blooms and the suspended particles from agricultural runoff and mining waste; **Ae**, the reduced water transparency reduced the amount of light penetrating the water, altering the visual environment of the bay. In the past, female tilapia showed a strong preference for mating with yellow-coloured and blue-coloured males because their colours were clearly visible in the clear water; however, as the water became turbid, female tilapia could no longer easily distinguish these colours, so the yellow and blue males lost their reproductive advantage; at the same time, hybrid brown tilapia, which had not previously been observed, became more common, hence the appearance and dominance of hybrid brown tilapia; **Ap**

Mercury biomagnification, food chain contamination and decline in fish-eating birds

Mercury concentration increased along the food chain lowest in water and highest in fish-eating birds; **AI**, due to the upstream gold-mining operation releasing waste containing mercury into the river system that drains into the bay; **Ae**, mercury is a heavy metal that is fat-soluble and is not easily broken down or excreted by organisms; when algae absorb mercury from the water, they accumulate it in their tissues; when small herbivorous fish eat many algae, they accumulate the mercury from all their food; when predatory fish eat many small fish, they accumulate even higher concentrations and when fish-eating birds eat many predatory fish, they accumulate the highest concentrations; this process of biomagnification along the food chain resulted in the highest mercury concentration in the top predator, the

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fish-eating birds; which resulted in the decline of fish-eating birds and the disruption of the aquatic food web in Mabamba Bay; **Ap**

b) Enforce buffer strips of vegetation along the lake shore and rivers to trap nutrients and mercury before they enter the bay

It is **effective**; **EI**, the vegetation traps sediments, nutrients (nitrogen and phosphorus) and mercury before they enter the bay; this reduces eutrophication, lowers the frequency of algal blooms and reduces the oxygen demand from decomposing algae, so dissolved oxygen levels can recover, supporting the survival, feeding, growth and reproductive success of native tilapia; however, buffer strips take time to become established and enforcement may also be difficult where agriculture and mining are the main livelihoods; **Ee**, therefore, this strategy should be implemented with farmer and miner training on sustainable practices and regular monitoring of water quality to track improvements; **Ep**

Regulate the use of fertilisers and require treatment of mining waste before discharge

It is effective; **EI**, it reduces the amount of nitrogen and phosphorus entering the bay, lowering eutrophication and algal bloom frequency, and it reduces the amount of mercury entering the river system, lowering biomagnification along the food chain; however, regulation requires enforcement, monitoring and penalties for non-compliance; **Ee**, therefore, this strategy should be implemented with clear regulations, regular monitoring and enforcement; **Ep**

Establish protected breeding zones where fishing is restricted during spawning seasons

It is effective; **EI**, it allows native tilapia and other fish species to spawn and reproduce without disturbance from fishing during the spawning season; this increases the number of eggs laid and the number of fry that survive to adulthood, helping to rebuild native tilapia populations and restore the yellow and blue colour forms; however, restricting fishing may reduce the income of local fishing communities during the spawning season, and enforcement may be difficult without community support and adequate patrols; **Ee**, therefore, this strategy should be implemented with alternative livelihood options for affected fishers during the closed season, clear boundary demarcation and regular monitoring of breeding success; **Ep**

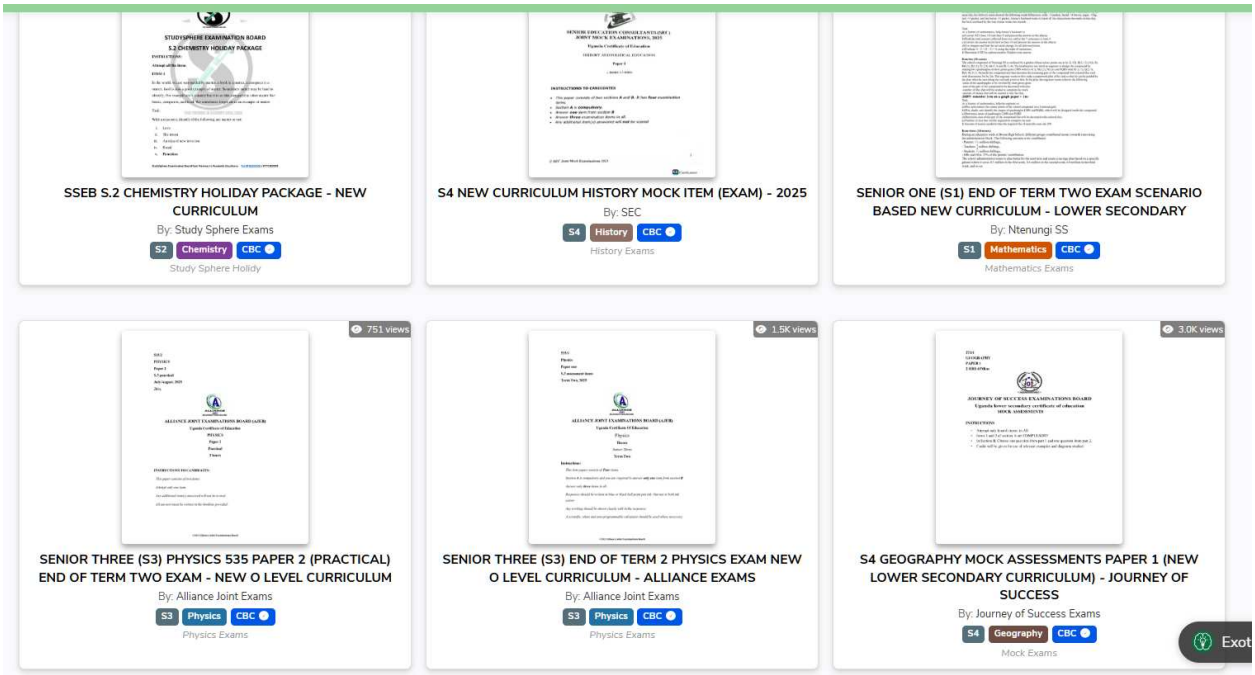
Monitoring water quality regularly to track changes in dissolved oxygen, nutrient and mercury levels

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It is effective; **EI**, it provides early warning of changes in dissolved oxygen, nutrient and mercury levels, allowing conservation officers to detect problems such as eutrophication and mercury contamination before they cause widespread damage, enabling timely intervention; however, monitoring requires equipment, trained personnel and long-term commitment; **Ee**, therefore, this strategy should be implemented with training of local personnel and regular sampling at multiple sites; **Ep**

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