

BirdSO Green Generation C 2021 Key

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Points:	17	5	6	6	6	6	6	3	13	7
Score:										

Page:	11	12	13	14	15	16	17	18	19	Total
Points:	8	10	4	4	7	5	13	16	6	148
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For questions 1 through 17, write "T" or "F" in the line provided corresponding to the statement being true or false.

1. F Biomass partitioning across trophic levels always follows a pyramidal distribution. [1]
2. F Deep-ocean stony coral rely on zooxanthellae to provide energy through photosynthesis. [1]
3. T Diazotrophs are the primary route for making atmospheric nitrogen available to plants. [1]
4. F Disease is a density-independent form of population control. [1]
5. T Food web linkage patterns tend to evolve over time. [1]
6. T White smokers typically have lower temperatures than black smokers. [1]
7. F Carbon dioxide is the most abundant greenhouse gas in Earth's atmosphere. [1]
8. F It is possible to directly attribute declines in fish stocks to either natural or human factors. [1]
9. F Seamount fisheries are typically sustainable for long periods of time. [1]
10. T Survival of juvenile salmon whose migrations pass through diversion dams is higher in conditions with higher water flow rates. [1]
11. T The number of extinctions due to habitat loss is higher because extinction processes are non-random than it would be if extinction processes were random. [1]
12. T Unpolluted rain has a pH above 5.7. [1]
13. T Economic obstacles to carbon capture and storage are currently more significant than technological barriers. [1]
14. F Phytoremediation is only effective for organic pollutants. [1]
15. F Power systems with higher renewable energy production tend to be inverter-dominated a lower fraction of the time. [1]
16. T The reintroduction of beavers to ecosystems is likely to help restore wetlands. [1]
17. T The use of bacteria for environmental cleanup is more common than the use of plants. [1]

For questions 18 through 55, circle the best answer from the four options listed.

18. Bottom feeders gaining energy through consumption of marine snow would best be described as which of the following? [1]
A. detritivores
B. parasites
C. predators
D. producers
19. Coastal environments make up about 12% of the area of the oceans. What percentage of net primary productivity do they contribute? [1]
A. 6
B. 12
C. 18
D. 24
20. How would you expect the population of a prey species to be impacted if the population of one of its predators increased? [1]
A. the prey population size would decrease
B. the prey population size would be unchanged
C. the prey population size would increase
D. the prey population size would remain the same but its age structure would change
21. The Lotka-Volterra equations are a model of a dynamical biological system consisting of which of the following? [1]
A. one species experiencing exponential growth
B. one species experiencing logistic growth
C. two species interacting through commensalism
D. two species interacting through a predator-prey relationship
22. The oxygen minimum zone in the ocean typically occurs at what depths? [1]
A. 0-10 meters below the surface
B. 50-100 meters below the surface
C. 200-1000 meters below the surface
D. close to the seafloor

23. The paradox of enrichment in population ecology refers to a situation where which of the following occurs? [1]
- A. primary consumer populations decrease due to an increase in consumable producers
 - B. primary consumer populations increase due to an increase in consumable producers
 - C. secondary consumer populations decrease due to an increase in consumable producers**
 - D. secondary consumer populations increase due to an increase in consumable producers
24. The primary source of dissolved organic carbon in an anchialine ecosystem is typically which of the following? [1]
- A. aquatic
 - B. terrestrial**
 - C. meteoric
 - D. none of the above
25. Which of the following correctly matches the type of life with its typical abundance in seawater? [1]
- A. 10 million bacteria per mL of seawater
 - B. 100 million bacteria per mL of seawater
 - C. 10 million viruses per mL of seawater**
 - D. 100 million viruses per mL of seawater
26. Which of the following is the best explanation for why an inverted biomass pyramid might occur? [1]
- A. conservation of energy does not apply to living things
 - B. energy is imported into the community from elsewhere**
 - C. the second law of thermodynamics does not apply to living things
 - D. inverted biomass pyramids do not occur
27. Why is freshwater inflow in Gulf of Mexico estuaries such an important factor for oyster populations? [1]
- A. decreased freshwater inflow makes the Gulf of Mexico less saline, which is unfavorable for the Florida stone crab, a major oyster food source
 - B. decreased freshwater inflow makes the Gulf of Mexico more saline, which is unfavorable for the Florida stone crab, a major oyster food source
 - C. decreased freshwater inflow makes the Gulf of Mexico less saline, which is unfavorable for the Florida stone crab, a major oyster predator
 - D. decreased freshwater inflow makes the Gulf of Mexico more saline, which is unfavorable for the Florida stone crab, a major oyster predator**
28. Why has herbivory on seagrasses historically been assumed to be infrequent and insignificant for biogeochemical cycles? [1]
- A. most seagrasses grow in regions of very low biodiversity
 - B. only a limited number of marine species are able to consume seagrasses**
 - C. seagrasses are most widespread in areas where they are invasive, meaning they have no natural consumers
 - D. seagrasses have very low primary productivity

29. Approximately what percentage of annual anthropogenic carbon dioxide emissions is currently absorbed by the oceans? [1]
- A. 5
 - B. 25**
 - C. 45
 - D. 65
30. A dead zone in the Gulf of Mexico tends to occur each year in what season? [1]
- A. winter
 - B. spring
 - C. summer**
 - D. fall
31. Coastal eutrophication is least likely to produce which of the following impacts? [1]
- A. enhanced nutrient recycling of N and P**
 - B. formation of hypoxic zones
 - C. loss of seagrasses
 - D. proliferation of harmful phytoplankton
32. For most commercial fished species, the maximum sustainable yield is what proportion of the unfished abundance? [1]
- A. 5-25%
 - B. 20-50%**
 - C. 40-70%
 - D. 60-95%
33. The largest measured hypoxic zone recorded in the northern Gulf of Mexico was approximately what area, in square kilometers? [1]
- A. 600
 - B. 11900
 - C. 22700**
 - D. 35900
34. The population of lesser snow geese wintering in Canada has dramatically increased over time, resulting in loss of vegetation and impacting many other species. Which of the following is the most likely reason for their population growth? [1]
- A. changes in agricultural practices in the southern extent of their ranges have enhanced their growth rate**
 - B. lesser snow geese are an invasive species in Canada
 - C. predators of lesser snow geese have substantially declined, reducing mortality
 - D. warmer summers have produced more vegetation in Canada, enhancing their growth rate

35. What impact does the presence of a thermocline tend to have on marine primary production? [1]
- A. a thermocline promotes mixing of deep waters with waters in the photic zone, promoting primary production
 - B. a thermocline promotes mixing of deep waters with waters in the photic zone, suppressing primary production
 - C. a thermocline suppresses mixing of deep waters with waters in the photic zone, promoting primary production
 - D. a thermocline suppresses mixing of deep waters with waters in the photic zone, suppressing primary production**
36. Which of the following is not likely to worsen the impacts of coastal eutrophication? [1]
- A. declines in oyster stocks
 - B. increased agricultural use of fertilizer
 - C. increased particle trapping by benthic plants**
 - D. loss of tidal marshes
37. Simulations have indicated that radioactive pollutants from the Fukushima nuclear accident were most likely carried to the US by winds within 5 days of the disaster. How is the concentration of pollutants reaching the US estimated to have compared to that near the Fukushima Nuclear Power Plant? [1]
- A. concentration reaching the US was smaller by 7 orders of magnitude**
 - B. concentration reaching the US was smaller by 5 orders of magnitude
 - C. concentration reaching the US was smaller by 3 orders of magnitude
 - D. concentration reaching the US was smaller by 1 order of magnitude
38. When the spatial pattern of decline in several Californian amphibian taxa was mapped, many species were observed to be in decline primarily downwind of agricultural land. This indicates the most likely driving factor for amphibian decline is which of the following? [1]
- A. airborne pesticide use**
 - B. climate change
 - C. habitat destruction
 - D. ultraviolet radiation
39. Ethiopian efforts to construct a hydroelectric dam on the Nile have faced significant opposition due to which of the following? [1]
- A. colonial-era treaties regarding water rights
 - B. differences in rainfall levels between upper and lower Nile countries
 - C. high water scarcity in the Nile region
 - D. all of the above**
40. Which of the following is not a likely effect of acid rain? [1]
- A. declines in fish stocks
 - B. enhanced deposition of calcium carbonate**
 - C. loss of lake biodiversity
 - D. release of inorganic aluminum into soils

41. On average globally, how do current atmospheric mercury deposition rates compare to those prior to the industrial era? [1]
- A. half as high
 - B. unchanged
 - C. four times as high**
 - D. ten times as high
42. The dominant source of Particulate Organic Aerosols to date is which of the following? [1]
- A. domestic wood burning**
 - B. forest fires
 - C. fossil fuel combustion
 - D. fungal spores
43. The main anthropogenic sources of atmospheric mercury are which of the following? [1]
- A. coal combustion and gold mining**
 - B. coal combustion and deforestation
 - C. deforestation and gold mining
 - D. there are no anthropogenic sources of atmospheric mercury
44. Which of the following best describes the main mechanism for lead contamination of wheat plants? [1]
- A. lead mainly enters via the atmosphere because above-ground plant parts provide a weaker barrier to lead than roots**
 - B. lead mainly enters via the atmosphere because lead concentrations are higher in the atmosphere
 - C. lead mainly enters via the soil because roots provide a weaker barrier to lead than above-ground plant parts
 - D. lead mainly enters via the soil because lead concentrations are higher in the soil
45. Analysis of renewable and non-renewable energy consumption in "Belt and Road Initiative" countries has found which of the following factors to best promote renewable energy generation? [1]
- A. economic growth
 - B. financial development**
 - C. foreign direct investment
 - D. technological innovation
46. Constructed wetlands are most frequently used for which of the following? [1]
- A. agricultural production
 - B. energy generation
 - C. wastewater treatment**
 - D. none of the above

47. Enhanced vegetation in urban environments can contribute to improvements in urban air quality. Which of the following forms of vegetation has been found to be most effective for improving air quality in street canyons? [1]
- A. green roofs
 - B. green walls
 - C. hedges**
 - D. trees
48. What is the cost of phytoremediation compared to engineering-based remediation methods like soil washing? [1]
- A. 100 times cheaper
 - B. 10 times cheaper**
 - C. 2 times cheaper
 - D. the same price
49. Which of the following is an organic pollutant which may be degraded through phytoremediation? [1]
- A. benzene**
 - B. nitrate
 - C. phosphate
 - D. none of the above
50. Which of the following is not an environmental benefit of domestic gardens? [1]
- A. encouraging peat accumulation**
 - B. improving localized air cooling
 - C. mitigating flooding
 - D. reducing domestic energy use
51. Which of the following is not a possible change to power grids to help them cope with very high penetration of variable renewable energy? [1]
- A. enhanced use of carbon capture technologies**
 - B. expansion of transmission networks
 - C. geographic diversity of variable renewable energy generators
 - D. investment in large-scale energy storage
52. Which of the following lists the steps of an environmental impact assessment in the appropriate order? [1]
- A. impact assessment, mitigation, project baseline, monitoring
 - B. project baseline, impact assessment, monitoring, mitigation
 - C. project baseline, impact assessment, mitigation, monitoring**
 - D. project baseline, mitigation, impact assessment, monitoring

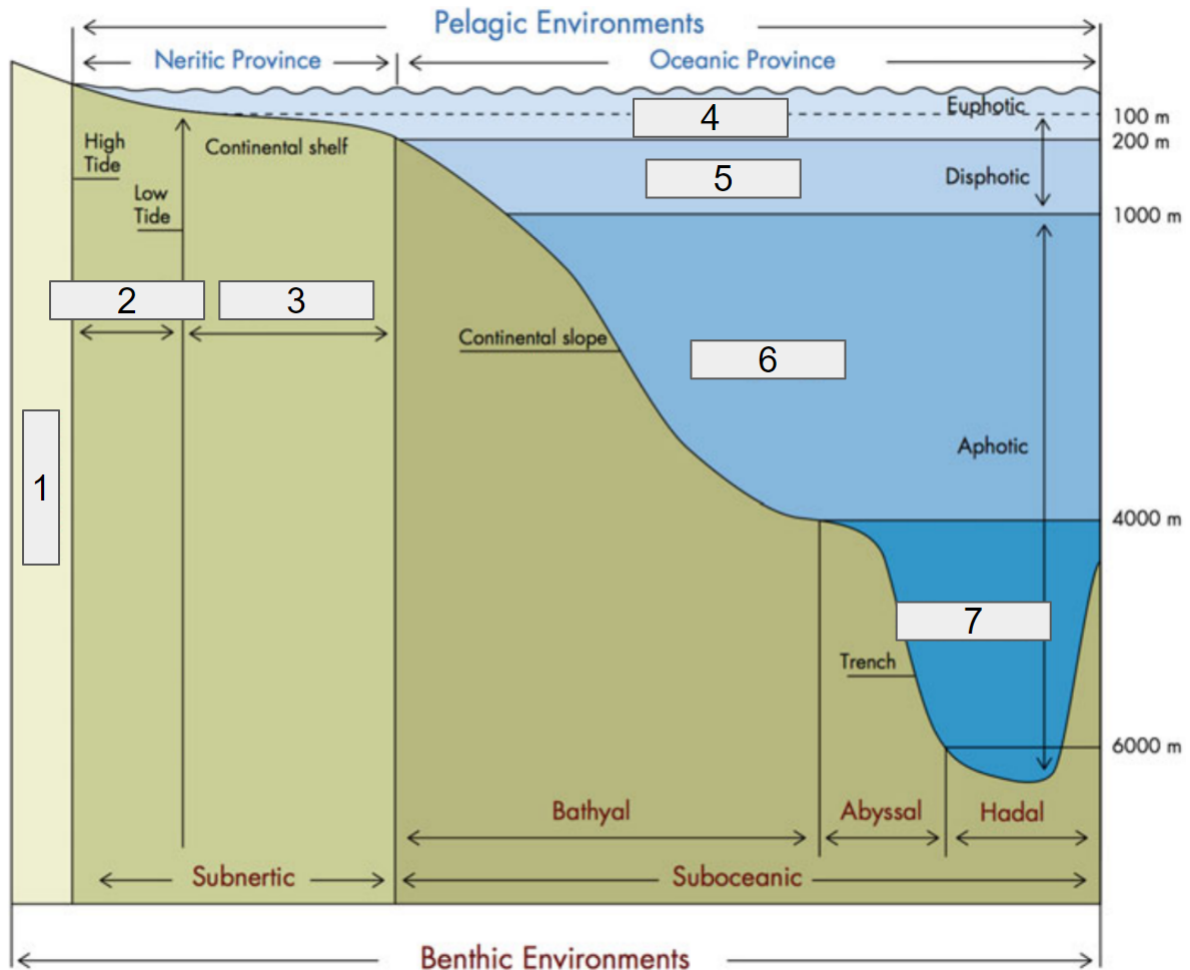
53. Which of the following would least likely be a goal of a stream restoration project? [1]
- A. increasing dissolved oxygen levels
 - B. narrowing riparian buffers**
 - C. promoting aquatic biodiversity
 - D. reducing pollutant levels
54. Which of the following is not a benefit of the use of nanofibers for immobilization of microorganisms in bioremediation applications? [1]
- A. enhanced catalytic activity
 - B. improved reusability
 - C. increased mass transfer resistance**
 - D. safer preservation of bacteria
55. Which of the following is not a reason for higher opposition to aquaculture of Pacific white shrimp than of channel catfish? [1]
- A. shrimp farming requires the use of more wild-caught larvae than catfish farming
 - B. shrimp feed requires more fish meal than catfish feed
 - C. shrimp ponds tend to be located in more ecologically sensitive sites than catfish ponds
 - D. shrimp ponds must be aerated more intensively than catfish ponds**

For questions 56 through 61, write the appropriate term in the line provided.

56. A food chain is a series of links in a community from autotrophic organisms to successive levels of heterotrophic organisms. When there are many of these, interconnected, they form a food web. [2]
57. Diatoms are a type of phytoplankton notable for their cell walls made of silica. [1]
58. The Redfield ratio is generally stated as 106 C : 16 N : 1 P. [3]
59. Evidence from lake cores indicates that fluctuations in Alaskan salmon abundance on time scales of multiple decades have occurred for a long time, in a long-term weather pattern known as the Pacific Decadal Oscillation (abbreviated PDO). [3]
60. Recruitment refers to the total number of juvenile fish entering a fish stock. [1]
61. The health of a fish stock with major fluctuations in abundance is typically measured through spawning stock biomass (abbreviated SSB), meaning the total weight of all fish beyond the age in which 50% of individuals are mature. [3]

For questions 62 through 75, write the answer in the lines or space provided.

62. Consider the following diagram of pelagic and littoral environments. Provide the correct label for the regions numbered 1-7 from left to right. [7]



1 supralittoral 2 littoral

3 sublittoral 4 epipelagic

5 mesopelagic 6 bathypelagic

7 hado/abyssopelagic

63. Name the 4 estuary typologies based on geomorphology.

[4]

Solution: bar-built or lagoon; drowned river valley or coastal plain; fjord; tectonic

64. The Getz categorization of consumers involves ten terms for consumers (bestivore, carcasivore, detritivore, decomposer, lectivore, necrophage, sarcophage, thanatophage, victivore, zontanophage) which refer to the consumption of five different categories of food sources (live and dead animals, live and dead plants, and particulate matter) and has two names for consumers of each of these depending on whether the consumers are moving or sessile.

List the two terms each for consumers of

(a) live animals: bestivore sarcophage

[2]

(b) dead plants: lectivore thanatophage

[2]

65. A simple mathematical model of predator-prey relations uses the coupled set of differential equations given below.

$$\frac{da(t)}{dt} = a(t)[\lambda b(t) - \mu]$$

$$\frac{db(t)}{dt} = b(t)[\sigma - \lambda a(t)]$$

$a(t)$ is the predator population density at time t , $b(t)$ is the prey population density at time t , λ is a constant parameter describing the rate of predation, μ is a constant parameter describing the predator death rate, and σ is a constant parameter describing the prey reproduction rate.

For a particular community, the predation rate is 0.3 per year, the prey reproduction rate is 0.2 per year, and the predator mortality rate is 0.4 per year.

- (a) The model lists a predator mortality rate, but not a prey mortality rate. Does the model necessarily assume that all prey are consumed by predators, rather than any dying for other reasons? Explain why or why not. [2]

Solution: No, the constant parameter describing the prey reproduction rate σ takes into account the prey mortality rate in the absence of predators.

- (b) If in a given year, the prey population density is 2 per acre, and the predator population density is 0.3 per acre, what is the instantaneous growth rates (in animals per acre per year) of each of the populations? [3]

Solution: $\frac{db}{dt} = 2 \times (0.2 - 0.3 \times 0.3) = 0.22$ prey animals per acre per year

$\frac{da}{dt} = 0.3 \times (0.3 \times 2 - 0.4) = 0.06$ predator animals per acre per year

[1 point each for exact values 0.22 and 0.06, 1 point for correctly labelling which value refers to which population]

- (c) There are several stable states for this predator-prey mathematical model. One of these involves both predator and prey populations being zero, and one involves predator populations being zero while prey populations become infinite. There is a third stable state for which both predator and prey population densities are nonzero. By setting $\frac{da(t)}{dt}$ and $\frac{db(t)}{dt}$ to 0, find the population densities of each of the populations at this nonzero stable point. [3]

Solution: $0 = a(0.3b - 0.4)$ means $b = 4/3$ is the prey population in the stable state.

$0 = b(0.2 - 0.3a)$ means $a = 2/3$ is the predator population in the stable state.

[1 point each for exact fraction or rounded/truncated decimal values 1.33 and 0.66/0.67, 1 point for correctly labelling which value refers to which population]

- (d) Which of the 3 stable states listed above is unrealistic? [1]

Solution: It is unrealistic for the prey population to become infinite.

[The answer that the state found in the previous part is not realistically stable, due to perturbations occurring in real situations, may also be marked correct. It is realistically possible for both species to go extinct.]

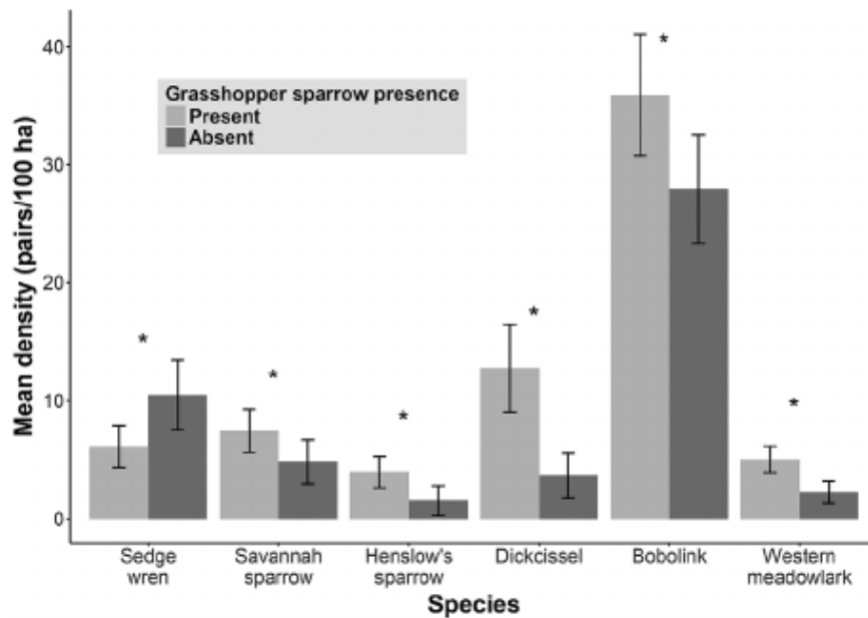
- (e) An adjusted model replaces the prey growth rate equation with [1]

$$\frac{db(t)}{dt} = \sigma b(t)[1 - \frac{b(t)}{\rho}] - \lambda a(t)b(t)$$

What does ρ represent in this equation?

Solution: ρ is the carrying capacity for the prey population [the finite population the prey would eventually attain in the absence of predators].

66. The image below shows the density of different prairie bird species in regions with and without grasshopper sparrows.



- (a) What percentage of the other prairie bird species are more common in regions with grasshopper sparrows? [2]

Solution: $5/6 = 83.3\%$ [1 point for a value between 80% and 87%, 2 points for 83% or a more accurate decimal.]

- (b) The grasshopper sparrow is a dry prairie specialist, and therefore is the most positive predictor for other dry prairie specialists. Based on this, which of the above species is most likely to be associated with wet prairies? [1]

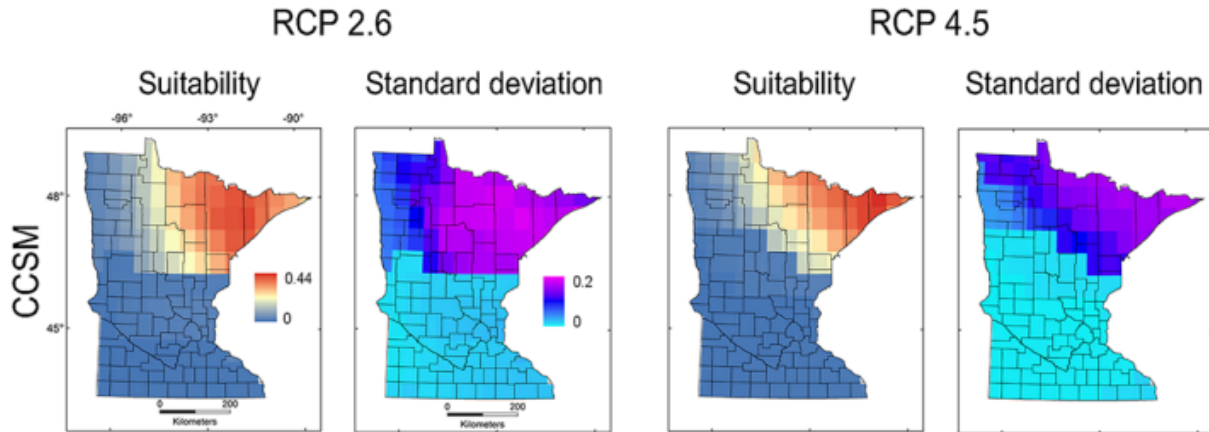
Solution: Sedge wren

[The Sedge wren is more common in regions without grasshopper sparrows, and wet prairies are also likely to be regions without grasshopper sparrows.]

- (c) Does it generally provide better information regarding overall biodiversity to monitor only one indicator species, or multiple? [1]

Solution: Multiple indicator species will provide better information regarding overall biodiversity.

67. The image below shows the predicted suitable range for the invasive alga starry stonewort in Minnesota under the RCP 2.6 and RCP 4.5 predictions.



- (a) Which of these two climate scenarios would have higher average temperatures? [1]

Solution: RCP 4.5 would have higher average temperatures.

- (b) In which direction is the range of starry stonewort predicted to shift in the warmer temperature climate scenario? [1]

Solution: The range of starry stonewort is predicted to shift toward the north (or the north-east) in the RCP 4.5 scenario.

- (c) Given current temperatures are cooler than both the RCP 2.6 and RCP 4.5 scenarios, is the range of starry stonewort in Minnesota most likely predicted to increase, decrease, or remain the same in the future? [1]

Solution: range in Minnesota will decrease in the future as temperatures warm

- (d) Starry stonewort is an aquatic species native to Europe and Japan. What is a likely method by which it arrived in the US (including Minnesota)? [1]

Solution: Starry stonewort is believed to have been introduced to the use through dumping of ship ballast water [but a more general answer mentioning ships in some way is acceptable].

68. One formula for the radiative forcing due to an increase in CO₂ concentrations by a factor β is given by

$$F_{\beta \text{ CO}_2} = 5.2 \ln \beta \text{ W m}^{-2}.$$

The black-body feedback on Earth is approximately $3.2 \text{ W m}^{-2} \text{ K}^{-1}$.

- (a) What is the radiative forcing associated with doubling atmospheric CO₂ concentrations? [2]

Solution: $5.2 \ln 2 = 3.60 \text{ W m}^{-2}$

[1 point for a value between 3 and 4, 2 points for 3.6 or a more accurate decimal]

- (b) CO₂ has a warming effect on the atmosphere due to its absorption in what general range of the electromagnetic spectrum? [1]

Solution: infrared region [or if wavelengths are given, a value on the order of 1000 nm]

- (c) Most of the absorption lines in carbon dioxide in Earth's atmosphere are strong absorption lines. Would the climate sensitivity of Earth to carbon dioxide be higher, lower, or unchanged if carbon dioxide's spectrum consisted of weaker absorption lines (with the same total equivalent width)? [1]

Solution: The climate sensitivity would be higher.

[This part has been changed to make its intention clearer than in the original exam on Scilympiad.]

- (d) If the only feedback process were blackbody feedback, what would the climate sensitivity to a doubling of CO₂ be, for the radiative forcing calculated in part a? [2]

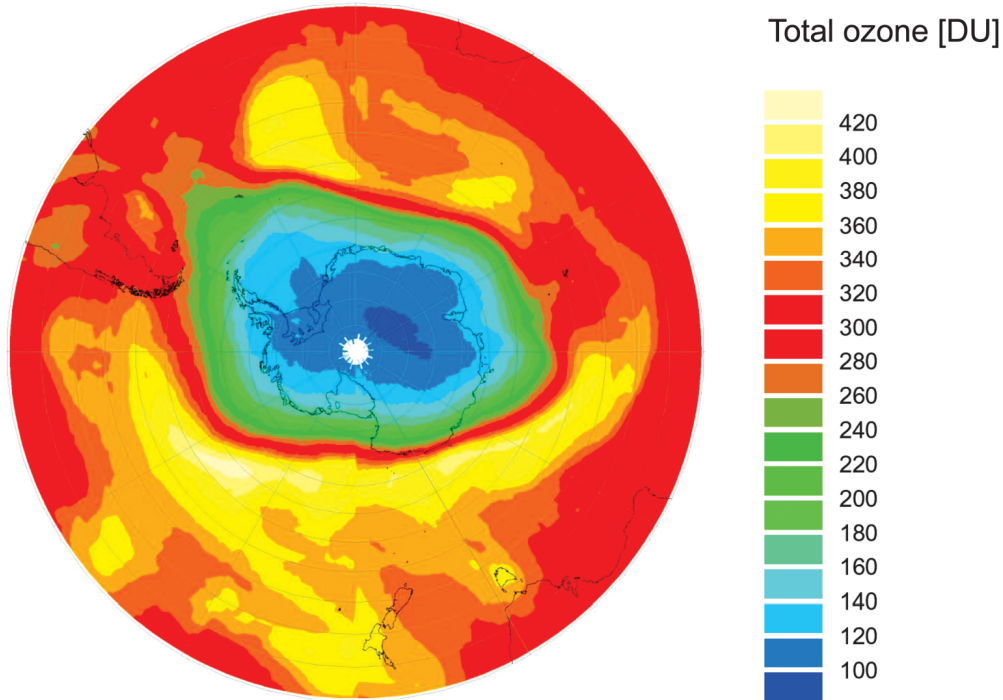
Solution: $3.6 \text{ W m}^{-2} / 3.2 \text{ W m}^{-2} \text{ K}^{-1} = 1.1 \text{ K}$

[1 point for 1.1 or more accurate decimal, 1 point for units of Kelvin or Celsius]

- (e) For chlorofluorocarbons, would the radiative forcing increase logarithmically with concentration, as in the formula above? [1]

Solution: No, the radiative forcing of chlorofluorocarbons does not increase logarithmically with concentration.

69. The image below shows measurements of total column ozone across the southern hemisphere.



(a) What do the units "DU" stand for, in the context of ozone? [1]

Solution: Dobson Units

(b) What is the approximate minimum column ozone shown in the image? [1]

Solution: accept any value between 80 and 100

(c) The Brewer-Dobson circulation governs movement of ozone throughout the stratosphere. Is ozone most likely circulated poleward or equatorward? [1]

Solution: poleward

(d) The Antarctic ozone hole is more severe than that in the northern hemisphere, at least in part due to wind patterns that differ between the northern and southern hemisphere. In which direction has the southern hemisphere tropospheric jet shifted due to the particularly severe Antarctic ozone hole? [1]

Solution: South [ie poleward]

(e) What is the term for the splitting of oxygen molecules into atomic oxygen by ultraviolet radiation, one of the steps of the ozone cycle leading to ozone formation? [1]

Solution: accept photolysis, photodissociation, or photodecomposition

70. The Wangyu River is a dual-source water diversion project connecting the Yangtze River and Taihu Lake. A 2020 research project monitored the levels of perfluoroalkyl acids (PFAAs) throughout this water diversion project.

- (a) As a persistent organic pollutant, perfluorooctanesulfonic acid (PFOS) is listed under which international environmental treaty? [1]

Solution: Stockholm Convention [on Persistent Organic Pollutants]

- (b) In 2020, $6.6 \times 10^8 \text{ m}^3$ of water was diverted from the Yangtze River, of which $2.4 \times 10^8 \text{ m}^3$ was eventually diverted into Taihu Lake. What percentage of the diverted water reached Taihu Lake? [2]

Solution: $2.4 \times 10^8 / 6.6 \times 10^8 = 36.4\%$ of diverted water reached Taihu Lake

[1 point for a value between 30% and 40%, 2 points for 36.4% or a more accurate decimal]

- (c) The concentration of perfluoroalkyl carboxylic acids (PFCAs), a type of PFAS, was measured as 88.3 ng/L at the Yangtze River end of the Wangyu River and 172.2 ng/L at the Taihu Lake end. By what percentage did the concentration of PFCAs increase during water diversion? Suggest a possible source of this additional PFCA pollution. [3]

Solution: $172.2/88.3 = 195\%$

95% increase in PFCA concentration

[1 point for a value between 90% and 100%, 1 point for 195%, 2 points for 95% or a more accurate decimal]

likely sources include tributaries or canals, and various point source and non point source

[1 point for any common pollution source, regardless of connection to PFCAs]

- (d) Using the values given above for the volume of water diverted and the concentrations, what mass of PFCAs entered Taihu Lake from the Wangyu River in 2020? [2]

Solution: $2.4 \times 10^8 \text{ m}^3 \times 172.2 \times 10^{-9} \text{ g/L} \times 10^3 \text{ L/m}^3 = 41300 \text{ g} = 41.3 \text{ kg} = 4.13 \times 10^{13} \text{ ng}$

[2 points for 41 kg or more accurate decimal or equivalent units, 1 point for incorrect order of magnitude or missing units]

71. Write the number corresponding to the acronym for a piece of environmental legislation in the space corresponding to the description of the legislation.

1) CERCLA 2) CLRTAP 3) MARPOL 4) NEPA 5) TSCA

- (a) IMO convention to reduce ocean pollution [1]

(a) 3) MARPOL

- (b) UNECE convention framework for setting reduction targets on air pollution [1]

(b) 2) CLRTAP

- (c) US law regulating the introduction of potentially harmful new chemicals [1]

(c) 5) TSCA

- (d) US law requiring widespread use of environmental impact statements [1]

(d) 4) NEPA

- (e) US program to identify and remediate toxic contaminated sites [1]

(e) 1) CERCLA

72. Place in order (by name or number) the sequence of the mitigation hierarchy in environmental impact assessments: [5]

1) avoidance 2) compensation 3) minimization 4) offsetting 5) rectification

Solution: 1, 3, 5, 2, 4; or avoidance, minimization, rectification, compensation, offsetting

[award 1 point for each number or name in correct place]

73. Place the following energy technologies (by name or number) in order from lowest death rate per TWh to highest death rate per TWh, considering deaths associated with both air pollution and industrial accidents. [6]

1) biomass 2) brown coal 3) coal 4) gas 5) nuclear 6) oil

Solution: 5, 4, 6, f, 3, 2; or nuclear, gas, biomass, oil, coal, brown coal

[award 1 point for each number or name in correct place]

74. The power incident on a hydroelectric turbine is given by the formula $P = \rho g Q h$, where P is power, ρ is density, g is gravitational acceleration, Q is volume per unit time, and h is the head, or height difference the water flows across.

- (a) What type of potential energy is converted into kinetic energy to turn the turbine? [1]

Solution: gravitational

- (b) The actual power output of a turbine is less than the incident power. Suggest 2 sources of energy losses. [2]

Solution: any of friction, kinetic energy remaining in water, loss of water from turbine radius, inefficiency in conversion to electricity

- (c) For a hydroelectric dam with a volumetric flow rate of $2 \text{ m}^3/\text{s}$ and 10 m head, what would the energy production be in the course of the year given an 80% overall efficiency? Give your answer in MWh. [2]

Solution: $P = 1000 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2 \times 2 \text{ m}^3/\text{s} \times 10 \text{ m} \times 80\% = 156800 \text{ W}$

$156800 \text{ W} \times 365 \text{ days} \times 24 \text{ hours/day} = 1373 \times 10^6 \text{ Wh} = 1373 \text{ MWh}$

[2 points for 1400 MWh or more accurate decimal, 1 point for incorrect order of magnitude]

75. The image below shows a chart of the half-lives of different polycyclic aromatic hydrocarbons (PAHs) undergoing oxidation by soil bacteria.

Table 4.5. Half-lives for the microbial degradation of PAHs in soil^a

Aromatic compound	Molecular weight	Half-life (weeks)
Naphthalene	128	2.4–4.4
Phenanthrene	178	4–18
2-Methylnaphthalene	142	14–20
Pyrene	202	34–90
3-Methylcholanthrene	226	87–200
Benzo[<i>a</i>]pyrene	252	200–300

- (a) Are all PAHs anthropogenic in origin?

[1]

Solution: No, there are natural sources of polycyclic aromatic hydrocarbons.

- (b) From the chart above, how does the rate of degradation of PAHs with more fused benzene rings compare to the rate of degradation of PAHs with fewer benzene rings?

[1]

Solution: PAHs with more fused benzene rings generally degrade more slowly [higher molecular weight PAHs generally have more fused benzene rings, and it is seen from the table that higher molecular weight PAHs have longer half-lives].

- (c) A soil is contaminated with 50 mg phenanthrene per gram of soil. How long do you expect it to take for this to be degraded by microbes to a contamination level of only 3 mg phenanthrene per gram of soil? Provide a range of values in weeks.

[2]

Solution: $3 = 50 \times (\frac{1}{2})^{t/\tau}$ where t is the degradation time and τ is the half-life of phenanthrene
 $t = \tau \times \log_2 \frac{50}{3} = 4.06 \times \tau$ results in a degradation time between 16.2 and 73.1 weeks.

[1 point each for values within 2 weeks of minimum and maximum estimates.]

- (d) Are PAHs highly soluble in water? Does this make it easier or harder for microorganisms to biodegrade PAHs, in general?

[2]

Solution: No, PAHs are not highly soluble, which makes it more difficult for microorganisms to biodegrade PAHs.

[2 points for no and harder, 1 point for no and easier, 1 point for yes and easier, 0 points for yes and harder]