Entrance Examination

For October 2019 and April 2020 students

Master's Course (Specialized subjects)

Notes

- Select and answer 3 QUESTIONS from the total 12 QUESTIONS. The 3 QUESTIONS can be selected from any subjects.
- One sheet should be used for each selected QUESTION. The reverse side could be used, if necessary.
- Name, examinee's number and course name should be written on each answer sheet.
- QUESTION number should also be written on each answer sheet.

Division of Biosphere Science

Graduate School of Environmental Science

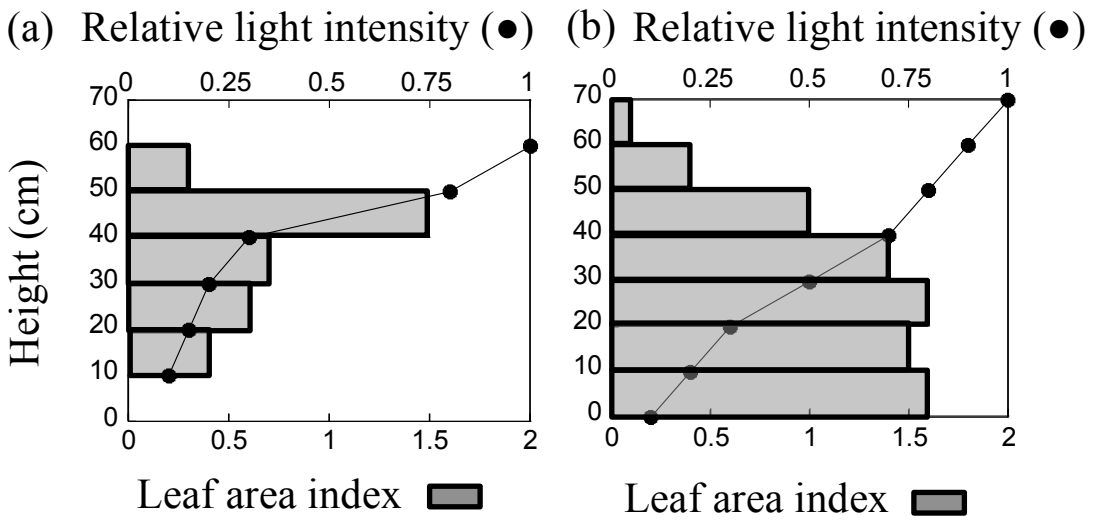
Hokkaido University

QUESTION 1 (Subject: Field Science)

Please answer the following questions after carefully examining the text below.

Light is essential for photosynthesis. It is absorbed by pigments such as chlorophylls in leaves. Light intensity generally decreases from the top to bottom leaf layer within a plant or population.

Question 1-1. The following figures, (**a**) and (**b**), illustrate the changing patterns of leaf area index (LAI, cumulative leaf area per unit ground area; "LAI = 1" indicates that a given ground area is covered by the same area of leaves) and relative light intensity (where light intensity at the top layer is expressed as 1) with height above the ground within a plant population. Please determine which figure belongs to a broad-leaved herbaceous population (*Xanthium occidentale*) and which to a linear-leaved grass population (*Moliniopsis japonica*), and explain the basis for the patterns of LAI and relative light intensity specific to each leaf type.



(modified from Seitaigaku-nyuumon, The Ecological Society of Japan, Ed., Tokyo Kagaku Dojin)

Question 1-2. Please explain one of the general morphological characteristics of plants growing in shady environments, such as the understory of a forest.

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Question 1-3. To acquire more light, a plant within a population must elongate its stems to expand leaves above the rest of the population. Please name two kinds of costs associated with stem elongation and state reasons why such costs are necessary.

Question 1-3. Perception of neighboring plants is important for increasing light reception and photosynthetic production. Please state the name of the photoreceptor used for perception of neighboring plants, and explain how this photoreceptor regulates stem elongation.

QUESTION 2 (Subject: Field Science)

Please answer the following questions after carefully examining the text below.

Establishment of protected areas plays a pivotal role in biodiversity conservation. Generally, larger protected areas are considered to be better because (a)they support more species and larger populations of individual species, which are more likely to persist for longer. It has also been suggested that (b)circular protected areas are better than narrower ones, (c) multiple protected areas should be established, and (d) these areas should be linked by habitat corridors. However, in real-world conservation planning, the opportunity to apply such guidelines is constrained by costs and the pattern of land-use history. For example, if the area available for conservation is limited, (e) it may be necessary to choose between a few large or many small protected areas.

Question 2-1. For underlined text (**a**), describe a graph of the relationship between the number of species S (Y-axis) and area A (X-axis). Also, derive the mathematical relation between S (number of species) and A (area) to which any constant can be added.

Question 2-2. For underlined text (**b**), explain the reason(s) why circular rather than narrow protected areas are preferable, using the term "edge effect".

Question 2-3. For underlined text (**c**), explain the reason(s) why multiple, not individual, protected areas are preferable.

Question 2-4. For underlined text (**d**), what benefit is expected from the use of habitat corridors?

Question 2-5. For underlined text (**e**), the optimal design strategy to apply depends on the characteristics of target species. Describe the species characteristics for which each conservation strategy becomes effective.

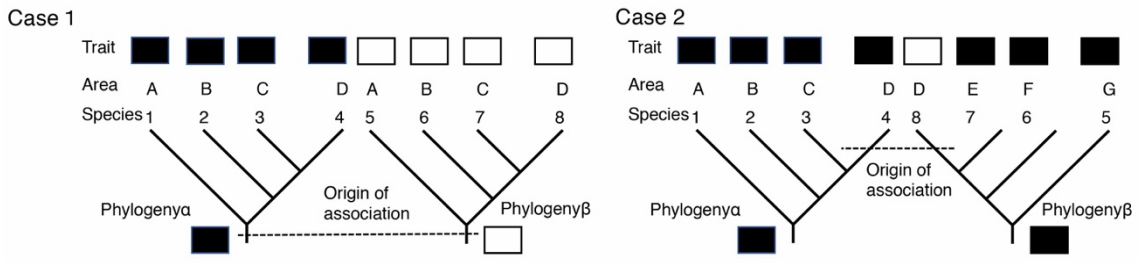
QUESTION 3 (Subject: Field Science)

Please answer the following questions after carefully examining the text below.

Question 3-1. All organisms (microbes, fungi, plants, and animals) interact with other species (organism) in a given space (habitat). For example, "interspecific interaction" is a typical type of interaction that occurs between two species competing for a food resource or space. Explain the four other direct interactions possible between a pair of species, giving one example of each interaction type.

Question 3-2. Some species that use similar resources nonetheless co-exist within an area. The "limiting similarity of niche" concept is traditionally used to explain the mechanism for such coexistence. Briefly explain the mechanism for coexistence of competing species according to that concept.

Question 3-3. This question is about phylogeography and evolution. In the two cases shown in the figure, phylogenetic trees of species 1–8 are shown for two phylogenies, along with the distribution areas of the species (areas A–D or A–G) and traits or niches concerning a resource used by the species, which are indicated by the color of the square. For example, species 1 is distributed in area A and has the "black" trait, whereas species 5 is in area A and has the "white" trait for case 1. Thus, the origin of association between the two ancestral species occurred here in case 1, whereas the origin of association between species 4 and 8 occurred in area D during or after speciation in case 2. Assume that competitive exclusion for the resource occurs in this system. Describe the difference in the process of coexistence and trait evolution between cases 1 and 2. If needed, you may use the following terms: niche shift, interspecific competition, and immigration.



QUESTION 4 (Subject: Field Science)

Please answer the following questions after carefully examining the text below.

Suppose that we have cultivation equipment to grow a plankton population. In this system, an asexual plankton population grows, for which the density is N_t at time t.

$$\frac{dN_t}{dt} = r N_t \left(1 - \frac{N_t}{K}\right)$$

The dynamics of the plankton density follow the differential equation above, labeled "logistic growth model of population".

Question 4-1. The logistic growth model has two parameters, r and K. Name and describe these commonly used parameters in population ecology.

Question 4-2. Next, we cultivate the same plankton under the same conditions, except for a significant increase in the parameter K (i.e., K is very large relative to N). In this case, what is the growth pattern called?

Question 4-3. In general animal ecology, some textbooks introduce an ecological conjecture for animal life history, such as the "*r* and *K* (or *r*-*K*)'' selection hypothesis, which states that two contrasting types of life histories are typical for animals, depending on their environment. Note that the parameters r and K appear in the logistic growth model. What are the differences between r and K animal species? Describe the characteristics of *r*-type animals for each of the following items: growth rate, individual timing of reproduction, and lifetime number of offspring.

Question 4-4. Some ecology textbooks note that the scheme of *r*-*K* selection described in question (3) does not work when categorizing multiple species. For example, elephants might be relatively *K*-selective compared to mice, but elephants do not avoid intraspecific competition. Suppose that you are conducting a research project comparing multiple animal species under the context of *r*-*K* selection. How do you choose animal species for your life history comparison project?

QUESTION 5 (Subject: Life Science)

Read the following text and answer the questions below.

Cells and organelles are separated by biological membranes present at the boundary with the outside environment. Biological membranes contain lipids and proteins as their main components, and most of the lipid components are phospholipids. When a biological membrane is observed with an electron microscope, a triple-layer structure with a thickness of approximately (A) can be observed. This is called a unit membrane of a biological membrane. The current model structure of biological membranes is based on the (1) theory proposed by Singer and Nicolson in 1972. The basic structure is a lipid (2) layer, in which amphiphilic lipid molecules are arranged with their hydrophilic heads facing outward. The lipid component maintains a (3) state with a mixture of solid and liquid phases, allowing protein molecules to move freely to some extent.

Because the lipid component is hydrophobic, ions and charged (4) substances are unable to pass through the membrane. (a)Therefore, transporter proteins selectively regulate the import and export of substances across the membrane. In addition, glycolipids expose complex (5) chains toward the outside of the membrane, forming a characteristic surface structure, and are involved in various cellular processes, including the immune response and signal transduction. Many lipid components of biological membranes are known. (b)Lipid compositions differ significantly among species and growth conditions, and therefore relationships of lipids with specific cellular functions have been suggested.

Question 5-1. Fill in the most appropriate word(s) in blanks (1) to (5).

Question 5-2. Select the most appropriate thickness for blank (A) from the list below.

(a) 7–10 pm, (b) 7–10 nm, (c) 7–10 μm, (d) 7–10 mm, (e) 7–10 cm

Question 5-3. Name three chemical materials of the lipid components that form biological membranes.

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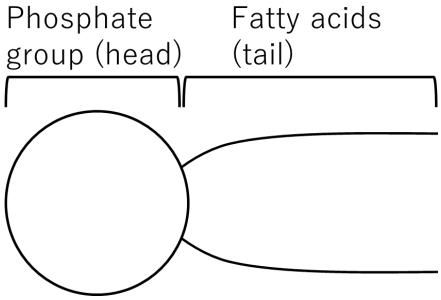
Question 5-4. Regarding underlined sentence (**a**), select five substances that can freely penetrate the biological membrane without the assistance of transporter proteins from the list below.

[Ca^{2+}, Cl^-, CO_2, fructose, glucose, glycerol, glycine, H^+, HCO_3^-, H_2O, K^+, Mg^{2+}, N_2, Na^+, O_2, sucrose]

Question 5-5. Phospholipids have an amphiphilic property due to their structure, with a head part containing the phosphate group and a fatty acid tail. The molecular structure of a phospholipid is represented in the following schematic diagram; use it to simply illustrate the basic structure of the biological membrane, as proposed by Singer and Nicolson.



Question 5-6. Regarding underlined sentence (**b**), a group of microorganisms called Archaea, which inhabit extreme environments such as high-temperature sites, have a unique membrane structure based on ether-type lipids with isoprenoids as the hydrophobic group. This structure is unlike those of Eubacteria and Eukaryotes, which utilize ester-type lipids with fatty acids for their biological membranes. Briefly explain (in about 100 words) why Archaea use these unusual lipid components in their biological membranes.

QUESTION 6 (Subject: Life Science)

Read the following sentences and choose the most appropriate word and phrase from the list for Questions 6-1 through 6-10. The list is provided after Question 6-10.

All organisms, from the simplest bacteria to humans, use the same basic mechanism of reading and expressing genes, a mechanism so fundamental to life as we know it that it is often referred to as **the Central Dogma.** Information passes from a gene (DNA) to an RNA copy of the gene, and the RNA copy directs the sequential assembly of a chain of amino acids.

Control of gene expression is essential to all organisms. In prokaryotes, it allows the cell to take advantage of changing environmental conditions. In multicellular eukaryotes, it is critical for directing development and maintaining homeostasis (Biology 7th ed., Raven et al.).

Question 6-1. What major RNA type is produced in the reaction mediated by RNA polymerase II in eukaryotes? Choose the most appropriate word or phrase from the list below.

Question 6-2. The three-nucleotide codon system can be arranged into _____ combinations. Choose the most appropriate number from the list below.

Question 6-3. What is the TATA box in eukaryotes? Choose the most appropriate word or phrase from the list below.

Question 6-4. The site where RNA polymerase attaches to the DNA molecule to begin the formation of RNA is called a(n) _____. Choose the most appropriate word or phrase from the list below.

Question 6-5. When mRNA leaves the cell's nucleus, it next associates with one moiety. Choose the most appropriate moiety from the list below.

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Question 6-6. Where do RNA sequences that contain information encoding a sequence of amino acids in eukaryotes reside? Choose the most appropriate word or phrase from the list below.

Question 6-7. Prokaryotes and eukaryotes use several methods to regulate gene expression. What is the most common of these methods? Choose the most appropriate word or phrase from the list below.

Question 6-8. The helix-turn-helix motif contains two helical segments, and in order for the motif to bind DNA, the _____ must fit into the major groove of the DNA. Choose the most appropriate word or phrase from the list below.

Question 6-9. In the prokaryotic genome, what is a name of a piece of DNA with a group of genes that are transcribed together as a unit? Choose the most appropriate word or phrase from the list below.

Question 6-10. What type of DNA sequence can be located far from a gene, but can promote its expression? Choose the most appropriate word or phrase from the list below.

List of words and phrases for Questions 6-1 through 6-10.

rRNA (ribosomal RNA), 16, -10 sequence, poly A tail, posttranscriptional control, transcriptional control, ribosome large subunit, zinc finger, paired domain, recognition helix, mRNA (messenger RNA), enhancer, 20, intron, exon, core promoter, promoter, operator, activator, ribosome small subunit, leucine zipper, UGAs, tRNA (transfer RNA), operon, MADS box, translational control, control of mRNA passage from the nucleus, 64, RNA polymerase, 5′-cap, 5′-UTR, GC hairpin, 128

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Answer the following questions.

Question 6-11. What effect would the addition of lactose have on a repressed *lac* operon?

a. It would reinforce the repression of that gene.
b. The operator site on the operon would move.
c. The lac operon would be transcribed.
d. It would have no effect whatsoever.

Question 6-12. Choose the correct phrase to complete the sentence.

DNA methylation of genes_____.

a. prevents transcription by blocking the TATA sequence.
b. inhibits transcription by blocking base-pairing between uracil and adenine.
c. inhibits transcription by blocking base-pairing between methylated cytosine and guanine.
d. ensures that genes that are turned off remain turned off.

Question 6-13. Which of the following statements about prokaryotic gene expression is correct?

a. Prokaryotic mRNAs contain the transcript of only one gene.
b. Prokaryotic mRNAs are often translated before transcription is complete.
c. Prokaryotic mRNAs must have introns spliced out.
d. All of these statements (a, b, c) are correct.
e. All of these statements (a, b, c) are incorrect.

Question 6-14. Multiple species of mRNA can be generated from a single gene through alternative splicing in eukaryotes. Describe alternative splicing in about 40 words.

Question 6-15. State an advantage for organisms of the mechanism of alternative splicing on the packaging efficiency of genomic information in about 20 words.

QUESTION 7 (Subject: Life Science)

Answer the following questions. Use the codon table as necessary.

Question 7-1. All amino acids share a common structure, containing an amino group, a carboxyl group, a hydrogen atom, and a variable group (R group).

(A) Draw the structural formula of the polypeptide with R groups of a hydrogen atom (glycine) and a methyl group (alanine) that are peptide bonded.

(B) What parts of a polypeptide participate in the bonds that hold its secondary structure together? What parts of a polypeptide participate in the bonds that hold its tertiary structure together?

Question 7-2. Translation, which takes genetic information from mRNA to protein, is RNA-directed synthesis of a polypeptide. What two processes ensure that the correct amino acid is added to a growing polypeptide chain?

Question 7-3.

(A) Draw a pattern diagram of a tRNA with the anticodon 3′-GCU-5′.

(B) In prokaryotes, this tRNA can bind to two codons due to a “wobble”. Sketch each codon on an mRNA, labeling all 5′ and 3′ ends.

Question 7-4. In the eukaryotic cell, once mRNA encoding a particular protein reaches the cytoplasm, what four mechanisms can regulate the amount of the protein that is active in the cell?

Question 7-5. Provide the characteristics of mammalian genomes that make them larger than prokaryotic genomes.

Question 7-6. How would sequencing the entire genome of an organism help scientists to understand how that organism functions? Answer in about 50 words.

QUESTION 8 (Subject: Life Science)

Read the text and answer the following questions.

Since Ancient Greece, scientists have recognized the phenomenon of heredity; i.e., a child resembles his or her parents. However, (a) only in the 20th century was the true genetic material identified as DNA. Deoxyribonucleotide, which is a single unit of DNA, comprises a pentose (deoxyribose), one of the four nitrogenous bases (adenine, guanine, thymine, and cytosine) and a phosphate group. The nitrogenous base forms a glycosidic bond to the (1)′ carbon of the deoxyribose, whereas the phosphate group forms an ester bond to the (2)′ carbon. Moreover, the (3)′ carbon is bonded to another deoxyribonucleotide, and thus the polymer of single-strand DNA is formed. In the cell, DNA polymerase uses deoxyribonucleoside triphosphates as substrates and a new reverse complement DNA strand is formed from the (4)′ end to (5)′ end of the template DNA strand. The complementary pairs of adenine and thymine form (6) hydrogen bonds and guanine and cytosine form (7) hydrogen bonds.

Genetic studies have advanced rapidly with the development of DNA sequencing technology. The most frequently used sequencing technology is dideoxy sequencing, which was developed by Frederick Sanger in 1977. First, a target DNA region for sequencing is amplified through PCR (polymerase chain reaction). The PCR product is mixed with labeled dideoxyribonucleoside triphosphates, on which the hydroxy group of the (8)′ carbon of the pentose is reduced. PCR is performed again. Labeled DNA fragments of various molecular weights are produced. Electrophoresis of these labeled products shows the nucleotide sequence based on the order of molecular weights.

Currently, numerous next-generation sequencing methods are being developed. In these methods, the electrophoresis step of the dideoxy sequencing method is removed, and parallel and rapid sequencing are achieved. For instance, (b) the luciferin-luciferase reaction is applied in the pyrosequencing method. The luciferase enzyme hydrolyzes ATP to AMP and (A). Luciferin is oxidized, resulting in luminescence. In the pyrosequencing method, single-chain DNA is used as the target template for sequencing, and (A) produced from one kind of deoxyribonucleoside triphosphate during PCR is converted to ATP. The converted ATP is then used in the luciferin-luciferase reaction as a substrate. Detecting luminescence from a different deoxyribonucleoside triphosphate

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allows rapid determination of nucleotide sequences. Next-generation sequencing technologies such as pyrosequencing have enabled (c)massive analyses of the genomes and transcriptomes of a variety of species.

Question 8-1. Fill in blanks (1) through (8) with the correct numbers.

Question 8-2. Fill in blank (A) with the correct word.

Question 8-3. In relation to underlined sentence (**a**), the Hershey-Chase experiment in 1952 demonstrated that the genetic material is DNA, not protein. They focused on differences in the constituent elements of DNA and protein and used bacteriophages labeled with radioisotopes to infect bacteria. Simply explain how they demonstrated that the genetic material is DNA using this method.

Question 8-4. With regard to underlined sentence (**b**), both polymerase chain reaction and the luciferin-luciferase reaction are energy-exchange systems using phosphoric acids in the cell. What organelle of eukaryotic cells plays a role in the production of an energy supply substance, ATP, through aerobic respiration? In addition, briefly explain the process of aerobic respiration using the following 6 terms:

glycolysis; Krebs cycle; electron transport chain; NADH; pyruvic acid; acetyl-CoA

*Note: Krebs cycle is also called the citric acid cycle or TCA cycle

Question 8-5. For underlined sentence (**b)**, transcriptome analysis in eukaryotes has revealed the presence of numerous ~20-bp functional non-coding RNA segments called microRNAs (miRNAs). The human genome contains at least 1,000 miRNA genes. miRNA is produced by the dicer enzyme through digestion of double-strand RNA. Simply explain the processes of miRNA production and the functions of miRNA, noting its relationship with mRNA (transcripts of protein-coding regions).

QUESTION 9 (Subject: Aquatic and Marine Science)

Read the following text related to phytoplankton ecology and marine ecosystems and answer each question below.

Phytoplankton in the ocean play a central role in marine ecosystems. Phytoplankton encompass a wide variety of functional groups and (a)sizes. Among phytoplankton, (b)diatoms are important carbon fixers, not only in coastal regions but also in the open ocean, as they account for 30–40% of global oceanic primary production. In particular, massive diatom blooms occur in the subarctic and (c)coastal upwelling regions. Therefore, investigating their bloom dynamics is essential to better understanding climate change, including global warming due to increasing carbon dioxide.

Question 9-1. Regarding underlined word (**a**), provide the regions where small- and large-sized phytoplankton are dominant, respectively, and explain the reason for this pattern in about 100 words, using the following keywords: surface area, volume.

Question 9-2. Referencing underlined term (**b**), explain the life cycle of diatoms in about 100 words, using the following keywords: asexual reproduction, sexual reproduction, auxospore formation.

Question 9-3. In regard to underlined phrase (**c**), one of the most famous coastal upwelling regions is off the coast of Peru, where El Niño often occurs. Explain the mechanism of the El Niño phase by comparison with the normal pattern, and describe the impact of El Niño on the marine ecosystem in about 150 words, using the following keywords: southeast trade winds, eastern equatorial Pacific, higher trophic levels of predators.

Question 10 (Subject: Aquatic and Marine Science)

Answer the following questions.

Many types of seaweed are distributed on the rocks in the intertidal and subtidal zones. The intertidal zone is exposed to air during low tide and covered with seawater when the tide is high. Seaweeds in the intertidal zone appear at a suitable tide level and form populations that exhibit vertical zonation. This pattern, i.e., the appearance and disappearance of seaweeds, shows the seasonal variation caused by the developmental stages of seaweeds. Meanwhile, the large seaweed *Sargassum* is detached from the substratum and becomes drifting seaweed, which produces a floating community harboring other organisms in offshore areas.

Question 10-1. Provide three environmental factors that influence the growth of seaweed in the intertidal zone.

Question 10-2. Briefly describe two ecological roles of drifting seaweeds.

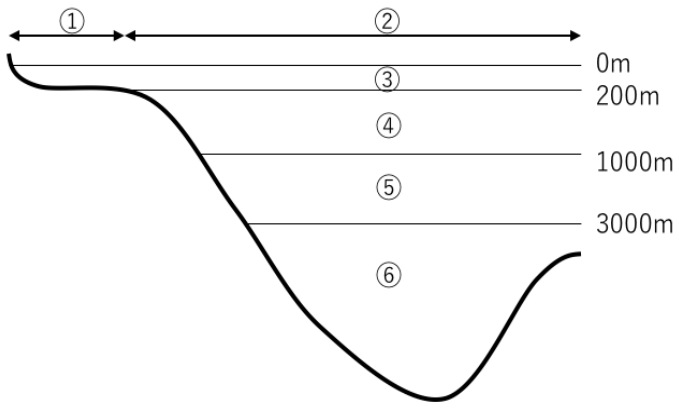
Question 10-3. Some seaweeds living at middle and high latitudes show morphological differences between high and low seawater temperature periods, which are related to their life cycle patterns. Answer the following questions.

(1) Explain isomorphic and heteromorphic alternation of generations.

(2) Describe the morphological differences between high and low water temperature periods according to the life cycles of specific seaweed species.

Question 11 (Subject: Aquatic and Marine Science)

Question 11-1. The following figure represents the oceanographic concept of vertical zonation in the ocean. Select the most appropriate word or phrase from the list below to fill in blanks ①-⑥.



*Note: The boundary between ⑤ and ⑥ may be defined as either 2,000 m or 4,000 m.

Lists of words or phrases: a) mesosphere, b) mesopelagic zone, c) convergence zone, d) troposphere, e) aphotic zone, f) bottom zone, g) transition zone, h) epipelagic zone, i) stratosphere, j) bathypelagic zone, k) boundary layer, l) abyssalpelagic zone, m) alluvium, n) shallow-sea area, o) neritic zone, p) polar sea region, q) oceanic zone, r) benthic province, s) Ekman layer, t) pelagic province

Question 11-2. Which area has higher productivity, ① or ②? Provide the reason for the difference between ① and ② in 20 words or less.

Question 11-3. For animals that inhabit ⑤ and/or ⑥, explain the following characteristics (1–4) using 30 words or less for each, and provide a reason for each.

(1) body color, (2) foraging, (3) reproduction, (4) growth

Question 11-4. How we can understand the ecology of deep-sea cephalopods, such as giant squid? Provide at least two examples other than deep-submergence vehicles and explain.

QUESTION 12 (Subject: Field Science)

Question 12-1. Read the following text carefully and select the most appropriate words and phrases from the list below to fill in the numbered blanks.

Propagation refers to means and techniques for recovering (1) in natural water areas or actively generating and maintaining natural resources. The purpose of propagation is to manage the environment and (2) of aquatic organisms in (3) and to improve (4) and (5). In addition, it aims to (6) the (7).

Propagation can be managed through the following three methods.

i) Establishment of (8) and (9), restriction and prohibition of (10) and (11)

ii) Increasing resources by massive (12) and (13) a large number of organisms' (14)

iii) Improvement of habitat for aquatic resources and increased (15) of (16) to support reproduction and growth. This method can aid the reproduction and growth of aquatic organisms, thus maintaining or increasing fishery resources.

The system developed based on the third method is (17) and (18).

List of words or phrases:

a) sea farming, b) reproduction, c) closed seasons, d) intermediate culture, e) seeds,
f) natural water areas, g) effect, h) growth, i) life, j) fishery resources,
k) aquaculture sea surface, l) marine ranches, m) public water surface, n) preserves,
o) drug registered for fishery use, p) fishing methods, q) transplanting,
r) fishing gear, s) fishery production, t) productivity, u) formula feed
v) maintain and increase, w) releasing

Question 12-2. Read the following sentences and fill in the blanks.

The dominant method has changed from (1) aquaculture to (2) aquaculture. Furthermore, sea farming aims to increase resources. However, a biological production system is needed that considers (3) biological production and effective use of resources in consideration of (4). Such production systems must employ the best method considering the economic impacts of climate, topography, water quality, and sales channels for products.

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As a basic measure of aquaculture in the 21st century, it is important to ensure the following items:

i) Construction of (5) systems for fish and shellfish (e.g., eel, yellowtail, tuna).

ii) Water in the aquaculture environment water should not contain (6), nitrous acid, or other harmful substances above standard levels. In particular, the former (6) is excreted in fish urine and (7) and is harmful to fish and shellfish. Therefore, aquaculture systems have been developed to maintain aquaculture environment water without these harmful substances. For example, a (8) feeding system has been developed that contains nitrifying bacteria within a biofiltration membrane.

iii) Development of complex aquaculture systems using (9).

iv) Development of aquaculture systems (aquaponics) linked with (10).

v) Securing (11) and (12) of food.