

DESCRIPTION

TITLE OF THE INVENTION: ALGACULTURE SYSTEM CONNECTED TO MARINE STRUCTURE AND METHOD FOR CULTURING ALGAE USING SAME

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Technical Field

[0001] The present invention relates to an algaculture system connected to a marine structure and a method for culturing algae using the same.

10 Background Art

[0002] In order to solve the issue of global warming, the importance of aiming for “carbon neutrality”, that is, reducing greenhouse gas emissions to zero, has been raised both domestically and internationally. Possible strategies to achieve carbon neutrality can be roughly divided into two categories: (i) technology development and behavior
15 change to reduce anthropogenic CO₂ emissions; and (ii) development of negative emission technologies to capture and absorb CO₂ emitted into the environment.

[0003] However, compared with the strategy (i), the strategy (ii) of technology development has not progressed sufficiently, and radical research and development are
20 needed.

[0004] Meanwhile, natural processes (CO₂ fixation) carried out by macroalgae with respect to low concentrations of CO₂ present in the atmosphere are attracting attention. It is known that as shown in Table 1, algal (3G) biomass, to which macroalgae and
25 microalgae belong, has higher annual productivity than starch-carbohydrate (1G) and woody (2G) biomass, and macroalgae in particular have a significantly higher CO₂ fixation capacity and relatively simpler biomass energy production processes and production conditions compared with other biomass (Non-Patent Document 1).

30 [0005]
[Table 1]

	Starch-carbohydrate (1G)	Woody (2G)	Algal (3G)	
Raw materials	Agricultural products (Corn, etc.)	Forest (Cedar, etc.)	Microalgae (Spirulina, etc.)	Macroalgae (<i>Ecklonia cava ssp. kurome</i>)/(<i>Sargassum muticum</i>)
Biomass productivity (t/ha/year)	11	9	10~20	30/210
CO ₂ absorption and fixation amount per unit area (kg-CO ₂ /m ² /year)	1.6	0.84	1.5~2.9	3.3/6.1
CO ₂ fixation ratio	2.3	1	7.6	13/170
Production process of biomass energy	Simple	Complex (Lignin removal)	Simple	Simple
Problems	Competition with food	Land is needed	Land is needed, Risk of contamination, High cost	Expansion of seaweed beds
Production conditions	Sunlight, CO ₂ , freshwater, land, fertilizer, pesticides	Sunlight, CO ₂ , freshwater, land, fertilizer, pesticides	Sunlight, CO ₂ , freshwater/brackish water, land	Sunlight, CO ₂ , seawater

[0006] Japan is an island nation surrounded by seas and has an exclusive economic zone that is approximately 12 times the land area (ranked sixth in the world). For this reason, there are a large number of algal beds suitable for culturing macroalgae.

[0007] However, in order to achieve the above-mentioned carbon neutrality, it is important to expand algal beds, and it is desired to also improve the production efficiency of macroalgae in each algal bed. In addition, the maturation period of

macroalgae is limited to a part of the year. It is considered that this is far from achieving stable carbon neutrality throughout the year.

Related Art Document

5 Non-Patent Document

[0008] Non-Patent Document 1: Keiei Sensa, "Industrial Applications of Microalgae", Toray Corporate Business Research, Inc., December 2021, p. 5-9

Summary of Invention

10 Problem to be Solved by the Invention

[0009] The present invention is to solve the above-described issues, and it is an object thereof to provide an algaculture system connected to a marine structure and a method for culturing algae using the same, which are capable of culturing various species of algae such as macroalgae more efficiently and being adapted to various production
15 scales.

Means for Solving the Problem

[0010] The present invention provides an algaculture system, comprising:
an algaculture means that is immersed in seawater and to which algae are
20 fixed; and
an epiphytic substrate that is disposed below the algaculture means with a space between the epiphytic substrate and the algaculture means,
wherein the algaculture means is connected to a marine structure, and
a shortest distance between the sea surface and the epiphytic substrate is 3.0
25 m to 14.5 m.

[0011] In one embodiment, the algae are at least one species of macroalgae selected from the group consisting of brown algae of the family *Sargassaceae* and brown algae of the family *Laminariaceae*.

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[0012] In one embodiment, the algaculture means is connected to the marine structure

in a state of being suspended from the marine structure.

[0013] In one embodiment, the epiphytic substrate is disposed in seawater at a distance from the seafloor.

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[0014] In one embodiment, the marine structure is a floating offshore wind power device.

[0015] In one embodiment, the marine structure is a fixed-bottom offshore wind power device.

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[0016] In one embodiment, the marine structure is an underwater observatory.

[0017] The present invention also provides a method for culturing algae, comprising:
a step of fixing algae to the algaculture means in the algaculture system in water;

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a step of propagating the algae via conjugation on the epiphytic substrate in the algaculture system, by means of zoospores or fertilized eggs released from the algae; and

a step of harvesting the algae from both the algaculture means and the epiphytic substrate.

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[0018] In one embodiment, the algae are at least one species of macroalgae selected from the group consisting of *Sargassum horneri*, *Sargassum muticum*, *Sargassum micracanthum*, *Sargassum thunbergii*, *Sargassum siliquastrum*, *Sargassum piluliferum*, *Sargassum autumnale*, *Sargassum macrocarpum*, *Sargassum ringgoldianum ssp. coreanum*, *Sargassum yendoii*, *Sargassum patens*, *Saccharina japonica*, *Undaria pinnatifida*, *Eckloniopsis radicata*, *Eisenia bicyclis*, *Ecklonia cava ssp. kurome*, *Ecklonia cava*, and *Eisenia nipponica*.

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[0019] In one embodiment, the algae are continuously cultured throughout the year while switching the species thereof depending on a maturation period thereof.

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[0020] The present invention also provides a method for producing a raw material for bioethanol, comprising:

5 a step of fixing algae to the algaculture means in the algaculture system in water;

a step of propagating the algae via conjugation on the epiphytic substrate in the algaculture system, by means of zoospores or fertilized eggs released from the algae; and

a step of harvesting the algae as the raw material for bioethanol from both the algaculture means and the epiphytic substrate.

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Effects of the Invention

[0021] According to the present invention, algae such as macroalgae can be efficiently cultured by utilizing the space where a marine structure is installed. Also, no special machinery or the like is required for such culture. In addition, it is possible to culture
15 algae almost continuously throughout the year, and the resulting algae can be supplied more stably as a raw material for, for example, bioethanol.

[0022] Also, according to the present invention, through the culture of the aforementioned algae, a new habitat for marine organisms can be provided around the
20 marine structure. As a result, it is expected to contribute to the promotion of fisheries for harvesting such marine organisms and to the development of tourism industries utilizing such marine organisms.

Brief Description of Drawings

25 [0023] FIG. 1 is a schematic view showing an example of an algaculture system of the present invention, using a fixed-bottom offshore wind power device as the marine structure.

FIG. 2 is a schematic view showing another example of the algaculture system of the present invention, using floating offshore wind expression devices as the marine
30 structures.

FIG. 3 is a schematic view showing another example of the algaculture system

of the present invention, using fixed-bottom offshore wind power devices as the marine structures.

FIG. 4 is a view illustrating a state in which a new habitat for marine organisms is provided around the marine structures by culturing algae using the system shown in
5 FIG. 3.

FIG. 5 is a schematic view showing another example of the algaculture system of the present invention, using fixed-bottom offshore wind power devices including support columns whose outer circumferences are protected with covering members, as the marine structures.

10 FIG. 6(a) is a view illustrating a fixed-bottom offshore wind power device including a fixing rod disposed at a distance from the support column, which can be used instead of the fixed-bottom offshore wind power devices connected to the algaculture system shown in FIG. 5, and FIG. 6(b) is a view illustrating a fixed-bottom offshore wind power device including a fixing rod disposed in a partially buried state, which can be
15 used instead of the fixed-bottom offshore wind power devices connected to the algaculture system shown in FIG. 5.

FIG. 7 is a schematic view showing another example of the algaculture system of the present invention, using an underwater observatory as the marine structure.

FIG. 8 is a diagram showing a relationship between the species of macroalgae
20 that can be cultured using the algaculture system of the present invention and their maturation period (the time of maximum abundance) in Japan.

Description of Embodiments

[0024] 1. Algaculture System

25 The algaculture system of the present invention will be described with reference to the accompanying drawings. The constituent elements denoted by the same reference numerals in all the following drawings are the same as those shown in the other drawings.

30 [0025] FIG. 1 is a schematic view showing an example of an algaculture system of the present invention. An algaculture system (hereafter also simply referred to as a

“system”) 100 includes an algaculture means 110 and an epiphytic substrate 120.

[0026] The algaculture means 110 is immersed in seawater, and algae are fixed thereto in advance. The algaculture means 110 is, for example, in the form of a net, rope, or wire, and is made of materials such as synthetic fibers (e.g., nylon or polyester, or a combination thereof), natural fibers (e.g., hemp, cotton, silk, or straw, or a combination thereof), biodegradable plastics (e.g., polylactic acid (PLA), poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBH), polyglycolic acid (PGA), polybutylene adipate/terephthalate (PBAT), polyethylene terephthalate succinate (PETS), polybutylene succinate (PBS), polybutylene succinate adipate (PBSA), or polyvinyl alcohol (PVA), or a combination thereof), cellulose-based polymers, metals (e.g., stainless steel, tungsten, aluminum, or copper, or a combination thereof), or the like. Preferred examples of the algaculture means 110 include a fishing net. If the algaculture means 110 is a fishing net, none of the thickness (*gou*), the mesh size (*sunme*), the number of meshes in the vertical direction (*kake*), and the size in the horizontal direction (*ken*) of the fishing net are limited, and the number and the size of fishing nets may be selected as appropriate by those skilled in the art.

[0027] Algae 106 to be cultured are fixed to the algaculture means 110. The algae 106 that are fixed may be of a single species or two or more species in a combination. For example, the algae 106 are fixed by attaching them beforehand to a thread known to those skilled in the art (e.g., Cremona (vinylon) thread) and winding the thread around the algaculture means 110.

[0028] The algae 106 grow in seawater. In the present invention, it is preferable that the algae 106 are macroalgae for the reason that they have a high CO₂ fixation capacity as described above.

[0029] There is no particular limitation on the algae 106 belonging to macroalgae, but examples thereof include those belonging to brown algae of the family *Sargassaceae* and brown algae of the family *Laminariaceae*.

[0030] There is no particular limitation on the algae 106 belonging to macroalgae, but examples thereof include *Sargassum horneri*, *Sargassum muticum*, *Sargassum micracanthum*, *Sargassum thunbergii*, *Sargassum siliquastrum*, *Sargassum piluliferum*, *Sargassum autumnale*, *Sargassum macrocarpum*, *Sargassum ringgoldianum ssp. coreanum*, *Sargassum yendoii*, *Sargassum patens*, *Saccharina japonica*, *Undaria pinnatifida*, *Eckloniopsis radicata*, *Eisenia bicyclis*, *Ecklonia cava*, *Ecklonia cava ssp. kurome*, *Eisenia nipponica*, *Heribaudiella fluviatilis*, and *Sargassum thunbergii*, and combinations thereof.

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[0031] As the algae 106 belonging to macroalgae that can be fixed to the algaculture means 110, those listed above may be used alone or in a combination of two or more according to their maturation period.

15 [0032] For example, from January to May in Japan, *Sargassum horneri* and *Sargassum muticum* may be used alone or in a combination as the algae 106.

[0033] From March to May in Japan, *Sargassum horneri*, *Sargassum muticum*, and *Sargassum micracanthum* may be used alone or in a combination as the algae 106.

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[0034] From June to August in Japan, *Sargassum thunbergii*, *Sargassum siliquastrum*, *Sargassum piluliferum*, *Sargassum yendoii*, *Sargassum patens*, *Sargassum macrocarpum*, *Sargassum ringgoldianum ssp. coreanum*, and *Eckloniopsis radicata* may be used alone or in a combination as the algae 106.

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[0035] From July to September in Japan, *Sargassum autumnale*, *Sargassum macrocarpum*, *Sargassum ringgoldianum ssp. coreanum*, *Eckloniopsis radicata*, *Eisenia bicyclis*, *Ecklonia cava ssp. kurome*, *Ecklonia cava*, and *Eisenia nipponica* may be used alone or in a combination as the algae 106.

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[0036] From September to November in Japan, *Sargassum autumnale*, *Sargassum*

macrocarpum, *Sargassum ringgoldianum ssp. coreanum*, *Eckloniopsis radicata*, *Eisenia bicyclis*, *Ecklonia cava ssp. kurome*, *Ecklonia cava*, and *Eisenia nipponica* may be used alone or in a combination as the algae 106.

5 [0037] From September to December in Japan, *Sargassum autumnale* may be used as the algae 106.

[0038] The algaculture means 110 is connected to a marine structure projecting from a sea surface 140. For example, in the embodiment shown in FIG. 1, the marine
10 structure is a fixed-bottom offshore wind power device 170 whose bottom is fixed to a seafloor 150, and the algaculture means 110 are connected in seawater to the fixed-bottom offshore wind power device 170 via a plurality of beam members 174 arranged around a support column 172 of the fixed-bottom offshore wind power device 170 at substantially constant angles in the same horizontal direction. In FIG. 1, multi-tier
15 beam members 174 are provided around the support column 172 of the fixed-bottom offshore wind power device 170, and the plurality of algaculture means 110 are arranged in a direction perpendicular to the support column 172. A plurality of algaculture means 110 may be arranged concentrically around the support column 172 so as to surround the support column, on the plurality of beam members 174 located in the same
20 horizontal plane around the support column 172.

[0039] In this manner, in the present invention, the algaculture means 110 can be arranged in both the directions that are perpendicular to and horizontal to the support column 172 of the fixed-bottom offshore wind power device 170, and thus the efficiency
25 (density) of the algae 106 cultured on the algaculture means 110 in a single system 100 can be increased.

[0040] The epiphytic substrate 120 is a man-made material that is disposed above the seafloor 150 in seawater 142, and is made of a relatively thin material having a
30 predetermined flat surface, such as a fabric, sheet, or plate having a predetermined thickness. Specifically, the epiphytic substrate 120 may be a woven, knitted, or non-

woven lignocellulosic fabric made of: synthetic fibers made of nylon or polyester; natural fibers such as hemp, cotton, silk, or straw; metal filaments made of stainless steel, tungsten, aluminum, or copper; fibers made of biodegradable plastics such as polylactic acid (PLA), poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBH), polyglycolic acid (PGA), polybutylene adipate/terephthalate (PBAT), polyethylene terephthalate succinate (PETS), polybutylene succinate (PBS), polybutylene succinate adipate (PBSA), or polyvinyl alcohol (PVA); fibers made of cellulose-based polymers; or a combination thereof, or may be a sheet or a plate (e.g., encompassing a hollow plate) made of thermoplastic resins (e.g., nylon or polyester, or a combination thereof), biodegradable plastics (e.g., polylactic acid (PLA), poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBH), polyglycolic acid (PGA), polybutylene adipate/terephthalate (PBAT), polyethylene terephthalate succinate (PETS), polybutylene succinate (PBS), polybutylene succinate adipate (PBSA), or polyvinyl alcohol (PVA), or a combination thereof), cellulose-based polymers, elastomer, or rubber, or a combination thereof.

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[0041] In FIG. 1, the attachment substrate 120 is disposed below the algaculture means 110 with a space therebetween. The epiphytic substrate 120 is disposed, for example, in a state of being suspended via wires 132 from the plurality of beam members 174 extending horizontally from the support column 172 of the fixed-bottom offshore wind power device 170. Alternatively, if the shortest distance between the sea surface 140 and the epiphytic substrate 120 is within a predetermined range as described later, the epiphytic substrate 120 may be disposed in direct contact with the seafloor 150.

25 [0042] There is no particular limitation on the thickness of the epiphytic substrate 120, but it is preferably 30 cm to 100 cm, and more preferably 50 cm to 70 cm. If the thickness of the epiphytic substrate 120 is less than 30 cm, disadvantages may arise such as the epiphytic substrate 120 not being strong enough or being easily swept away by water currents such as tidal currents. If the thickness of the epiphytic substrate 120 is more than 100 cm, the epiphytic substrate 120 may become heavier as a whole, which may increase the difficulty in placing it on the seafloor 150 and/or in retrieving and

recovering it from the seawater 142.

[0043] In the present invention, the epiphytic substrate 120 may be any one of those made of, for example, the above-mentioned fabrics, sheets and/or plurality of combined
5 plates that have been cut as appropriate.

[0044] There is no particular limitation on the size of the epiphytic substrate 120, but it is designed to be larger than the above-described algaculture means 110 suspended thereabove. In FIG. 1, the epiphytic substrate 120 is disposed around the support
10 column 172 of the fixed-bottom offshore wind power device 170 and has a circular shape, but it is not necessarily limited to this form. For example, the epiphytic substrate 120 may have a rectangular or polygonal shape and be disposed around the support column 172.

[0045] In the culture system 100 of the present invention, algae 106' are fixed
15 (attached) to the epiphytic substrate 120 via rhizoids (holdfasts). The algae 106' are not artificially arranged, but are naturally generated on the epiphytic substrate 120 from zoospores or fertilized eggs 160 released from the algae 106 suspended from the algaculture means 110. The algae 106' may be of the same species as the algae 106
20 suspended from the algaculture means 110, but may be those naturally generated from other zoospores or fertilized eggs that have drifted in the seawater 142 and been provided from the outside.

[0046] The algae 106 fixed to the algaculture means 110 release germ cells or fertilized
25 eggs 160 into the seawater 142 as they grow.

[0047] For example, if the algae 106 are brown algae of the family *Laminariaceae*, their sporophytes release zoospores, which are germ cells, and gametophytes. If the algae 106 are brown algae of the family *Sargassaceae*, they release fertilized eggs when
30 matured.

[0048] In the present invention, such zoospores (germ cells) and fertilized eggs released from the algae 106 can be caused to reach the epiphytic substrate 120. Subsequently, by means of the germ cells or fertilized eggs 160 that have reached the epiphytic substrate 120, the algae 106' are propagated "via conjugation" with the above-described algae 106, as a result of which the algae 106 and 106' can be propagated on both the algaculture means 110 and the epiphytic substrate 120 that is disposed therebelow.

[0049] A shortest distance D between the sea surface 140 and the epiphytic substrate 120 is not always limited because it varies depending on the species of seaweed to be cultured, the degree of seawater movement such as tidal currents at the culture site, and the like, but in a stationary state, it is 3.0 m to 14.5 m, and preferably 4.0 m to 10 m. If the shortest distance D between the sea surface 140 and the epiphytic substrate 120 is less than 3.0 m, the influence of tidal currents is likely to be exerted, and thus, for example, zoospores (germ cells) or fertilized eggs 160 released from the algae 106 may be excessively swept away by seawater currents such as tidal currents before they reach the epiphytic substrate 120 that is disposed therebelow, as a result of which it may be difficult to propagate the algae 106' via conjugation on the epiphytic substrate 120. If the shortest distance D between the sea surface 140 and the epiphytic substrate 120 is more than 14.5 m, the resulting depth may make it difficult for the epiphytic substrate 120 to receive the amount of sunlight necessary for the propagation of the algae 106'.

[0050] Furthermore, in the culture system 100 shown in FIG. 1, a plurality of light-emitting means 180 such as blue light-emitting diodes may be provided in any locations on the algaculture means 110, the beam members 174, the epiphytic member 120, and the like.

[0051] The light emitted from the light-emitting means 180 (e.g., light on the short-wavelength side, particularly from blue LEDs) is useful in that it can promote the propagation of the algae 106 and 106'. For example, even when the shortest distance D between the sea surface 140 and the epiphytic substrate 120 is within the above-mentioned range, an increase in the amount of light in the seawater 142 may be

required for further propagation of the algae 106 and 106'. Alternatively, the algae 106 and 106' can be irradiated with light as a supplement during nighttime or seasons with short daylight hours such as winter. The power for the light-emitting means 180 may be directly supplied, for example, from the fixed-bottom offshore wind power device that
5 is the marine structure 170.

[0052] FIG. 2 is a schematic view showing another example of the algaculture system of the present invention.

10 [0053] In an algaculture system 200 shown in FIG. 2, two floating offshore wind power devices 270 and 270' are used as the marine structures, and an algaculture means 210 and an epiphytic substrate 220 are provided between the floating offshore wind power devices 270 and 270' fixed in advance by fixing means 236 and 238 such as wires.

15 [0054] Ends 212 and 214 of the algaculture means 210 are respectively connected to the floating offshore wind power devices 270 and 270', and a plurality of floats 230 are fixed along the way. As a result, the algaculture means 210 has, as a whole, a plurality of gentle U-shaped bends and is disposed in a state of being suspended in the seawater
142.

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[0055] As in the system 100 shown in FIG. 1, the epiphytic substrate 220 is disposed below the algaculture means 210 with a space between the epiphytic substrate 220 and the algaculture means 210. The epiphytic substrate 220 is disposed in a state of being suspended from the floating offshore wind power devices 270 and 270' via wires 232 and
25 234 in the seawater 142.

[0056] The algae 106 are fixed to the algaculture means 210 in the same manner as described above, zoospores (germ cells) and fertilized eggs released from the algae 106 can be caused to reach the epiphytic substrate 220 disposed below. Subsequently, by
30 means of the germ cells or fertilized eggs 160 that have reached the epiphytic substrate 220, the algae 106' are propagated "via conjugation" with the above-described algae 106,

as a result of which the algae 106 and 106' can be propagated on both the algaculture means 210 and the epiphytic substrate 220 that is disposed therebelow.

5 [0057] The algaculture system 200 shown in FIG. 2 is used when propagating the algae 106 and 106' via conjugation in locations where the floating offshore wind power devices 270 and 270' are arranged as the marine structures even when it is difficult to arrange a fixed-bottom offshore wind power device as shown in FIG. 1 due to a long distance between the sea surface 140 and the seafloor 150.

10 [0058] FIG. 3 shows another example of the algaculture system of the present invention.

[0059] For example, in areas near the coast or in shallow waters, a plurality of fixed-bottom offshore wind power devices 370 and 370' may be arranged in advance as the
15 marine structures. An algaculture system 300 of the present invention can be disposed utilizing the regions formed between these plurality of fixed-bottom offshore wind power devices 370 and 370'. FIG. 3 shows an example in which an algaculture means 310 and an epiphytic substrate 320 are provided between two fixed-bottom offshore wind power devices 370 and 370' that are marine structures, but the present invention is not
20 limited to this form.

[0060] For example, as shown in FIG. 4, an algaculture system 400 of the present invention can be disposed between a larger number of marine structures (fixed-bottom offshore wind power devices) 470. In this case, an algaculture means 410 and an
25 epiphytic substrate 420 will occupy a more extensive region (large surface area), and the species and quantities of algae 106, 106' propagated via conjugation can also be expanded.

[0061] Furthermore, as the region, species, and quantities of algae 106, 106' propagated via conjugation are expanded, an environment conducive to the growth of
30 various marine organisms useful for fisheries, such as fish, shellfish, shrimp, crabs,

squid, and octopus, will be created in the surrounding area. As a result, the location where the algaculture system 400 of the present invention is disposed can be expected to yield the desired algae while also serving as a high-quality fishing ground.

5 [0062] Furthermore, even if the use of an offshore wind power device such as a fixed-bottom offshore wind power device is desired as a marine structure, it is anticipated that the direct fixation of the algaculture system of the present invention to the offshore wind expression device may be regulated or restricted due to safety reasons and/or other laws and regulations. In such cases, the algaculture system of the present invention can be
10 disposed without being directly fixed to the offshore wind power device, as shown, for example, in FIG. 5.

[0063] In the embodiment shown in FIG. 5, an algaculture system 500 of the present invention is configured such that covering members 575 are provided around the
15 respective outer circumferences of fixed-bottom offshore wind power devices 570, more specifically, around the respective outer circumferences of support columns 572 constituting the fixed-bottom offshore wind power devices 570. The covering members 575 allow the algaculture means 410 in the algaculture system 500 of the present invention to be indirectly fixed to the fixed-bottom offshore wind power devices 570
20 without direct contact, and is made of any water-resistant materials, for example. The thickness and the like of the covering members 575 are not particularly limited and may be appropriately set by those skilled in the art.

[0064] Alternatively, in the present invention, fixed-bottom offshore wind power
25 devices 670a and 670b as shown in FIGS. 6(a) and 6(b) may be used instead of the fixed-bottom offshore wind power devices 570 shown in FIG. 5.

[0065] The fixed-bottom offshore wind power device 670a shown in FIG. 6(a) includes a fixing rod 674a disposed at a distance from a support column 672a. The algaculture
30 means 410 in the culture system of the present invention is attached to the fixing rod 674a, and thus direct contact between the algaculture means 410 and the fixed-bottom

offshore wind power device 670a can be avoided.

[0066] Meanwhile, the fixed-bottom offshore wind power device 670b shown in FIG. 6(b) includes a fixing rod 674b disposed in a partially buried state around a support column 672b and at a distance from a support column 672b. The algaculture means 410 in the culture system of the present invention is attached to the fixing rod 674b, and thus direct contact between the algaculture means 410 and the fixed-bottom offshore wind power device 670b can be avoided.

[0067] FIG. 7 shows another example of the algaculture system of the present invention, illustrating an algaculture system 700 of the present invention using an underwater observatory 770 as the marine structure. The underwater observatory 770 includes a cylindrical tower section 772 that is disposed in seawater and allows observation of the underwater environment through an observation window 776, and an observation room 773 that is connected to the cylindrical tower section 772 and is disposed above the sea surface 140.

[0068] In the algaculture system 700 shown in FIG. 7, algaculture means 710 to which the algae 106 are fixed are connected to the underwater observatory 770 via a plurality of beam members 774 extending from the cylindrical tower section 772 of the underwater observatory 770. In the embodiment shown in FIG. 7, it is preferable that the beam members 774 and the algaculture means 710 are positioned above the observation window 776 provided in the cylindrical tower section 772 so as not to obstruct the view through the observation window 776.

[0069] Meanwhile, an epiphytic substrate 720 is disposed around the cylindrical tower section 772 of the underwater observatory 770. It is also preferable that the epiphytic substrate 720 is positioned below the observation window 776 provided in the cylindrical tower section 772 so as not to obstruct the view through the observation window 776.

Furthermore, on the epiphytic substrate 720, the algae 106' are present that are propagated by means of zoospores (reproductive cells) or fertilized eggs 160 released

from the algae 106 fixed to the algaculture means 710, and the algae 106 and 106' can be propagated via conjugation.

[0070] Since the algaculture system 700 shown in FIG. 7 has this configuration, an environment conducive to the gathering of many marine organisms such as fish can be created between the algae 106 fixed to the algaculture means 710 and the algae 106' grown on the epiphytic substrate 720. As a result, the algaculture system 700 of the present invention not only enables the culture of the desired algae 106 and 106' but also enhances the value of the underwater observatory 770 required as a tourist facility.

[0071] In the foregoing embodiment, the floating offshore wind expression devices, the fixed-bottom offshore wind power devices, and the underwater observatory were described as examples of the underwater structures, but the present invention is not limited thereto. For example, in addition to the above, the underwater structures may be an aquaculture raft (fish cage), an offshore bridge, a breakwater, a jetty, a wave-dissipating breakwater, a marine buoy (including navigational aids), an artificial island, or an offshore airport island. Furthermore, the underwater structures may be constructed near the coast or offshore (e.g., at a distance of about 2 km from the coast).

[0072] 2. Method for Culturing Algae

Next, a method for culturing algae of the present invention will be described.

[0073] In the method of the present invention, algae are first fixed to an algaculture means in the above-described algaculture system in seawater.

[0074] The algae fixed to the algaculture means are preferably germlings that have been pre-grown in a manner known to those skilled in the art. In the present invention, it is preferable to culture algae at an appropriately increased culture density in order to prevent the algae from being consumed by fish and shellfish, which can cause rocky-shore denudation. Algae such as macroalgae secrete bromophenols such as 2,4-dibromophenol and 2,4,6-tribromophenol outside the algal body when the culture

density is controlled. Such bromophenols function as chemical defense substances (repellents) against fish, shellfish, and other marine algae-eating animals, resulting in the avoidance of the above-mentioned rocky-shore denudation.

5 [0075] Subsequently, by means of germ cells or fertilized eggs released from the algae, the algae are propagated via conjugation on the epiphytic substrate in the algaculture system.

10 [0076] In the case of culturing algae (germlings) fixed to the algaculture means in the ocean, the release of germ cells or fertilized eggs from the algae is caused to occur by waiting for the algae themselves to spontaneously initiate the release after a predetermined period of time after placing them offshore (placing them in the sea). This predetermined period of time is not necessarily limited because it varies depending on the species of algae to be cultured, the time of year, and the culture environment (e.g.,
15 water temperature, culture density), but it is, for example, preferably 150 days to 360 days after the algae are fixed to the algaculture means (or placed offshore). Furthermore, the period of time from when the released germ cells or fertilized eggs are accepted by the epiphytic substrate to when the propagation via conjugation occurs is not necessarily limited because it also varies depending on the species of algae to be
20 cultured, the time of year, and the culture environment (e.g., water temperature, culture density), but it is, for example, preferably 30 days to 60 days after the germ cells or fertilized eggs are released from the algae.

25 [0077] Subsequently, algae are harvested from both the algaculture means and the epiphytic substrate.

[0078] That is to say, in the method of the present invention, target algae can be harvested not only from the algaculture means but also from the epiphytic substrate, and thus the amount of resulting algae harvested is significantly higher than when the
30 algaculture means is used alone.

[0079] In this manner, algaculture can be more efficiently performed.

[0080] The algae cultured by the above-described method can be used as, for example, a raw material for bioethanol, which can be obtained using the method described below.

5 If such algae are used as a raw material for bioethanol, it is desirable to be able to constantly obtain a certain amount of the raw material regardless of the season. In the present invention, different species of algae to be cultured are preferably selected according to the season in order to enable the constant availability of such a raw material for bioethanol.

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[0081] FIG. 8 is a diagram showing a relationship between the species of macroalgae that can be cultured using the algaculture system of the present invention and their maturation period (the time of maximum abundance) in Tohoku and regions south thereof in Japan.

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[0082] The macroalgae that can be cultured in the seas around Japan have different maturation periods depending on their species, and as a whole, at least any one of the algae can be obtained between January and December.

20 [0083] As shown in FIG. 8, for example, the months from January to May in Japan correspond to the maturation periods of *Sargassum horneri* and *Sargassum muticum*. The months from March to May in Japan correspond to the maturation periods of *Sargassum horneri*, *Sargassum muticum*, and *Sargassum micracanthum*. The months from June to August in Japan correspond to the maturation periods of
25 *Sargassum thunbergii*, *Sargassum siliquastrum*, *Sargassum piluliferum*, *Sargassum yendoii*, and *Sargassum patens*. The months from July to September in Japan correspond to the maturation periods of *Sargassum macrocarpum*, *Sargassum ringgoldianum* ssp. *coreanum*, and *Eckloniopsis radicata*. The months from
30 September to November in Japan correspond to the maturation periods of *Sargassum autumnale*, *Eisenia bicyclis*, *Ecklonia cava* ssp. *kurome*, *Ecklonia cava*, and *Eisenia nipponica*. The months from September to December in Japan correspond to the

maturation periods of *Sargassum autumnale*.

[0084] Therefore, for example, in Japan and its surrounding regions, it is possible to constantly produce the algae serving as a raw material for bioethanol throughout the
5 year from January to December, by appropriately selecting the algae to be cultured.

[0085] The algae (e.g., macroalgae) that can be obtained by the above-described process are rich in sugars such as cellulose, hemicellulose, alginic acid, mannitol, and laminaran. Ethanol (i.e., bioethanol) can be produced from the sugars that are thus contained in the
10 algae.

[0086] 3. Method for Producing Bioethanol

By using the algae cultured as described above as biomass, sugars (glucose, etc.) contained in the biomass can be used as a raw material for bioethanol. Methods for
15 producing bioethanol from a given sugar are known, and, for example, the method described in Japanese Laid-Open Patent Publication No. 2008-193935 can be used.

[0087] Bioethanol obtained by such a method can be used, for example, as an alternative automobile fuel to gasoline. In addition, since the bioethanol is produced
20 through algaculture as described above, there is no issue of competition with food production.

[0088] As mentioned above, the present invention makes it possible to constantly produce algae, which also enables a stable supply of the resulting bioethanol to the
25 market. Furthermore, since macroalgae with high CO₂ fixation capacity can be cultured, the present invention is also useful as a negative emission technology to capture and absorb CO₂ emitted into the environment. As a result, the present invention can also contribute to the realization of carbon neutrality.

30 Industrial Applicability

[0089] The present invention is useful, for example, for obtaining a raw material for

bioethanol production. The invention is also useful in other fields such as fisheries and tourism.

Reference Signs List

5	[0090]	100, 200, 300, 400, 500, 600, 700	Algaculture system
		106, 106'	Algae
		110, 210, 310, 410, 710	Algaculture means
		120, 220, 320, 420, 720	Epiphytic substrate
		132, 232, 234	Wire
10		140	Sea surface
		142	Seawater
		150	Seafloor
		160	Germ cells or fertilized eggs
		170, 370, 370', 470, 570, 670a, 670b	Fixed-bottom offshore wind power
15	device		
		172, 572, 672a, 672b	Support column
		174, 574	Beam member
		180	Light-emitting means
		230	Float
20		236, 238	Fixing means
		270, 270'	Floating offshore wind power device
		575	Covering member
		674a, 674b	Fixing rod
		770	Underwater observatory
25		772	Cylindrical tower section
		773	Observation room
		776	Observation window

CLAIMS

[Claim 1] An algaculture system, comprising:

an algaculture means that is immersed in seawater and to which algae are
5 fixed; and

an epiphytic substrate that is disposed below the algaculture means with a
space between the epiphytic substrate and the algaculture means,

wherein the algaculture means is connected to a marine structure, and

a shortest distance between the sea surface and the epiphytic substrate is 3.0
10 m to 14.5 m.

[Claim 2] The algaculture system according to claim 1, wherein the algae are at
least one species of macroalgae selected from the group consisting of brown algae of the
family *Sargassaceae* and brown algae of the family *Laminariaceae*.

15

[Claim 3] The algaculture system according to claim 1, wherein the algaculture
means is connected to the marine structure in a state of being suspended from the
marine structure.

20 [Claim 4] The algaculture system according to claim 1, wherein the epiphytic
substrate is disposed in seawater at a distance from the seafloor.

[Claim 5] The algaculture system according to claim 1, wherein the marine
structure is a floating offshore wind power device.

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[Claim 6] The algaculture system according to claim 1, wherein the marine
structure is a fixed-bottom offshore wind power device.

[Claim 7] The algaculture system according to claim 1, wherein the marine
30 structure is an underwater observatory.

[Claim 8] A method for culturing algae, comprising:

a step of fixing algae to the algaculture means in the algaculture system according to any one of claims 1 to 7 in water;

5 a step of propagating the algae via conjugation on the epiphytic substrate in the algaculture system, by means of zoospores or fertilized eggs released from the algae; and

a step of harvesting the algae from both the algaculture means and the epiphytic substrate.

[Claim 9] The method according to claim 8, wherein the algae are at least one

10 species of macroalgae selected from the group consisting of *Sargassum horneri*, *Sargassum muticum*, *Sargassum micracanthum*, *Sargassum thunbergii*, *Sargassum siliquastrum*, *Sargassum piluliferum*, *Sargassum autumnale*, *Sargassum macrocarpum*, *Sargassum ringgoldianum* ssp. *coreanum*, *Sargassum yendoii*, *Sargassum patens*, *Saccharina japonica*, *Undaria pinnatifida*, *Eckloniopsis radicata*,
15 *Eisenia bicyclis*, *Ecklonia cava* ssp. *kurome*, *Ecklonia cava*, and *Eisenia nipponica*.

[Claim 10] The method according to claim 8, wherein the algae are continuously cultured throughout the year while switching the species thereof depending on a maturation period thereof.

20

[Claim 11] A method for producing a raw material for bioethanol, comprising:

a step of fixing algae to the algaculture means in the algaculture system according to any one of claims 1 to 7 in water;

25 a step of propagating the algae via conjugation on the epiphytic substrate in the algaculture system, by means of zoospores or fertilized eggs released from the algae; and

a step of harvesting the algae as the raw material for bioethanol from both the algaculture means and the epiphytic substrate.