Wave upwelling pump development and dissemination project

<Exploring the Potential of Wave Forces for Ocean Fertilization and Typhoon Control>.

(1) Project Overview

This project is about the fertilization of the oceans and CO2 capture (blue carbon technology) by bringing nutrient-rich low-layer water to the surface without the use of anthropogenic energy.
At the same time, it concerns the possibility of developing technology to control typhoon (hurricane and cyclone) development by cooling sea surface temperatures in summer.

One means of pumping water from the seafloor to the surface and diffusing it at the sea surface using only wave power is artificial upwelling using a wave upwelling pump.
NPO ESCOT began in 2019 to develop a wave upwelling pump with a simple and widespread check valve system that does not require large-scale resource and energy input.

The world's fishing grounds are concentrated in upwelling areas (areas where low-layer seawater is pushed up to the surface due to the influence of currents, seafloor topography, etc.), which account for about 0.1% of the total area of the ocean, and are said to account for 50% of the global catch.
Offshore Peru, offshore California, and offshore Southwest Africa are known as upwelling areas.
In such waters, low-level water, which is richer in nutrients than sea surface water, rises to the surface (upwelling).

This photosynthesis leads to the production of phytoplankton, which in turn leads to secondary production of fish and other organisms, resulting in a good fishing ground.
If the upwelling area could be increased by another 0.1% with the least cost and resource/energy input, the world food problem would be greatly improved.
If artificial upwelling areas are created in coastal areas not far from land, the need to go out to sea will diminish, reducing fuel costs, risk, and workload for fishing vessels.

The overabundant phytoplankton capture large amounts of atmospheric CO2, which then reaches the end of its life span and is deposited and fixed on the seafloor in marine snow form.

In summer, when sea surface temperatures rise abnormally, if a large amount of low-temperature water can be pumped from the lower layers to lower sea surface temperatures, the amount of water vapor supplied to typhoons (hurricanes and cyclones) can be reduced and typhoon (hurricane and cyclone) damage can be mitigated.

In Japan, the frequency of large typhoons has increased, bringing a disaster scale of more than 1 trillion yen to eastern Japan in 2019.
Currently, it is known to power up rapidly when sea surface temperature rises above 26.5° C.

The wave upwelling pump is characterized by the fact that the higher the wave (amplitude), the greater the volume of low-level water pumped and the lower the surface water temperature.
In the case of Tokyo, from the time a typhoon is born about 1,000 km south of the city, its waves arrive in the surrounding waters as swell.
The upwelling of low-level cold water then begins, and the steam supply is automatically curtailed, in advance.

The project is still accumulating knowledge and data on equipment performance, upwelling efficiency analysis, and impact on the surrounding ecosystem.

(2) Project Background

There are concerns about food shortages due to increased damage to seaweed, coral, etc., and slumping coastal fisheries (reduced catches) caused by rising sea water temperatures.
In addition, the increase in sea surface temperature is considered to be a factor contributing to the development of typhoons (hurricanes and cyclones) due to the increased generation of water vapor, thereby increasing the risk of damage escalation.
Rising sea surface temperatures are also thought to be responsible for the increased frequency of heavy snowfalls in winter.
Surface seawater heated by global warming is thought to form a warm water cap on the sea surface, which acts as follows.

1. at a depth of about 0.5 to 1.0 m, about 50% of the thermal energy due to solar radiation

and air temperature is absorbed.
As a result, a warm water cap forms on the sea surface from summer to autumn in the seas around Japan.

The hot water cover prevents vertical agitation of the seawater for a long period of time, resulting in an oxygen-poor situation in the lower levels.

*In the case of lakes where temperatures do not drop during the winter, this causes circulation problems in the lake water and adversely affects the lake bottom ecosystem.

3. on the other hand, the hot water lid leads to a decrease in CO_2 absorption from the air to the ocean.

3-2. At the same time, the lack of vertical agitation of seawater hinders the upwelling of nutrients that have settled in the lower layers and rise to the sea surface.

4. lack of CO_2 and nutrients in the photosynthetic layer hinders photosynthesis by phytoplankton.

4-2. As a result, the function of biological production in the oceans will be significantly reduced, adding to global warming.

5. Also, when the hot water lid is above 26.5° C, the amount of water vapor supplied to typhoons (hurricanes and cyclones) increases, contributing to their larger size.

(3) Project Purpose and Motivation

In 2019, a large typhoon hit the suburbs of Tokyo, causing extensive damage mainly in Chiba Prefecture.
Subsequent investigations revealed that the sea surface temperature was abnormally high.
As a person who enjoys surfing and other marine sports, I knew the difference in water temperature between the sea surface and a few meters below it at skin level.
If the up-and-down motion of the waves could carry the seawater several meters below to the surface, could it be possible to suppress the growth of larger typhoons? I thought.
The difference in water temperature at a depth difference of only a few meters in shallow waters was not small.
Depending on the season, tidal range, and current conditions, divers may experience heart paralysis and death due to the difference in water temperature.
The project was motivated by the idea of pumping nutrients, including iron and other nutrients necessary for the growth of marine phytoplankton, and low-temperature water from the shallow ocean.

Subsequent research revealed that attempts at artificial upwelling had been made in many parts of the world.
However, most of them were beyond the scope of the study with methods that resulted in large-scale inputs of resources and energy.
In 2007, the University of Hawaii and the University of Oregon conducted a demonstration test in the open ocean off the coast of Hawaii, and the pump failed within a few days, exposing the difficulties of long-term upwelling pumps in the open ocean.
From the data they left us, we concluded that strength, durability, and appropriate size were the most important issues in the development of a wave upwelling pump.

(4) Project scope and implementation activities

The scope of this project includes shallow-water areas, lakes, and rivers around the world.
Experiments are currently ongoing at two locations in Chiba and Miyagi prefectures.
(1) Activities in Chiba Prefecture
We are conducting strength, efficiency, and aging tests of the equipment in a section of the Iwawada fishing port in Oyado, Chiba Prefecture, as well as investigating the effects of the equipment on the surrounding ecosystem and collecting water temperature data 50 cm above the sea surface, 50 cm below the sea surface, and at a water depth of 2 m.
In April of this year, the scope of the experiment is scheduled to be expanded to a 600-meter radius from the fishing port.
The purpose is to verify the strength durability against larger waves and to identify issues.
Therefore, we obtained permission from the head of the local administration and the cooperation and consent of the fishery cooperative.
In addition, the Japan Coast Guard is scheduled to exchange information on effective fixing methods.
(2) Activities in Miyagi Prefecture
Started a demonstration test of wave upwelling pumps at a local scallop and ascidian aquaculture farm in Same-no-ura Bay, Ishinomaki City, Miyagi Prefecture.
Two wave upwelling pumps (6m in length) were placed in the flylines for aquaculture, and a comparative study of growth was started.
At the same time, data is being collected from the seafloor (approx. 20 m depth), 5 m above the seafloor, 50 cm below the seafloor, and 50 cm above the sea surface to determine the effects of outside air and water temperature on growth.
The site is underway with the full cooperation of a youth group consisting of young local

fishermen.
The purpose of the experiment here was to improve the yield and quality of scallops and ascidians.

We believe that a less costly approach to typhoon (hurricane and cyclone) damage control is to result in increased adoption in the fisheries sector.

(5) Innovativeness of the project (innovation)

Papers on the importance and usefulness of wave upwelling pumps have been published by universities and research institutes around the world.
However, no examples of long-term verification tests in the ocean have been found since the large-scale experiment off the coast of Hawaii.
In the background, there are hurdles such as the risk burden of continuing experiments on the power and destructiveness of the ocean, as well as mutual understanding among the parties involved in obtaining permits and approvals, such as the competent government, fishery cooperatives, and the Japan Coast Guard.
With the understanding and cooperation of the fishery cooperative (Oyado Iwawada Fishery Cooperative Association), NPO ESCOT was allowed to use 1,200 m2 as a test sea area.
It was convenient to test the strength and durability of the device in a section of the harbor where fishing boats cannot moor due to the large waves that enter during typhoons.
In addition, the situation of being able to freely use this sea area for a long period of time has greatly expanded the scope of research and development of concepts that had been limited to wave pump analysis in the laboratory (joint research with Shibaura Institute of Technology).
One of the effects of these efforts has been the development of the world's first wide check valve, which has greatly improved the upwelling rate in small waves, and many other innovations.
We believe that the offshore testing of wave upwelling pumps will continue over the long term to produce technology to increase fisheries food production and reduce typhoon (hurricane and cyclone) damage.

New findings so far:.

(1) Overview of Innovation
We devised a method that can pump bottom water to the surface even in small waves of a few

centimeters.
*Large wave upwelling pumps have been used in demonstration tests conducted overseas.
*The size of many of these devices has presented many challenges in terms of maintenance, management, and durability performance.
*The structure of the check valve installed in the pipe inner diameter did not provide sufficient upwelling effect in water areas where small waves occur, such as bays and lakes.

(2) Innovations in equipment for wave upwelling pumps
New functions of wave upwelling pumps, previously unknown worldwide
<Slanting cut wide valve
*Slanted cut at the tip of the buoy to reduce fluid resistance during ascent and reduce buoy sinking loss.
*Pumped water was sent downstream of the ocean current to reduce the amount of low water re-sedimentation.
*The lower type, which is thicker than the upper pipe, is used to increase the diffusion area by increasing the flow velocity when draining.
＜Valve plug closing force mechanism
The valve is equipped with elastic side wings to improve the upwelling function at low amplitude.
<Adoption of float buoy with wind pipe
Wind-receiving pipes were installed diagonally on the buoys, and the pendulum motion of the buoys when they were knocked over due to wave slopes and wind was used to increase their upward ascent.
*The oscillating surface of the upwelling pump is fixed so that it is parallel to the wave, reducing energy loss due to twisting and precessional motion of the upwelling pump.
<Suspension rope in Yusho pump
*Ropes were hung inside the pipes through which the rising water passed to prevent shellfish from attaching to the inside.
*A chain or similar device was attached to the bottom of the above rope to promote the diffusion of sedimentation nutrients.
<High-strength, long-life, rustproof hinged valve
Special hinges are used that can withstand 20,000 to 40,000 openings and closings per day for more than one year.
(iii) Innovation in terms of dissemination, mobility, repair, removal, and disposal
*Commercial materials can be used for low-cost DIY installation.
*With the exception of check valves, sewage piping (VU pipes and fittings), which is available

anywhere, can be obtained at low cost as a global standard material.
Green materials such as used tires are used for the rubber wings and elastic materials for opening and closing the door.
*Easy sorting at the time of disposal by using a single material
(4) Collaboration with Stommel's permanent salt spring effect
In addition to wave force, seawater pumping effect is added due to the temperature difference of the upwelling pump pipe.
*The upwelling pipe receives heat from the warm seawater outside the pipe to warm the low-salinity deep seawater inside the pipe, and the buoyancy of the water causes the deep seawater to be pumped up.
By using this principle of permanent salt springs, it is possible to pump deep ocean water using only the difference in temperature and salinity of the ocean.

(6) Project Implementation and Costs

NPO ESCOT's wave upwelling pumps are technically simple.
Seawater pumping does not pump seawater to a position higher than the sea surface, but moves up and down in seawater, so no load is applied other than density difference and fluid friction due to the difference in water temperature.
The energy source is the potential energy of the waves to raise the floating structure and the upwelling pump tube suspended below it.

The component parts consist of a floating body on the water surface (buoy), a pipe with a check valve towed by a rope at the bottom of the buoy, and a rope hanging down inside the pipe to prevent shellfish from settling on the buoy.
The cost is about 300,000 yen per unit, including installation costs, for a wave upwelling pump of about 6 m in length, with an upper pipe inner diameter of 100 mm and a lower pipe inner diameter of 150 mm, which is currently used in scallop farms.

Possible economic benefits in the following categories
① Economic Effects in Fisheries Resource Revitalization
② Economic Benefits in the Disaster Prevention and Mitigation Sector
③ Economic benefits in the area of carbon pricing, including reductions in CO

(1) Economic effects in the revitalization of fishery resources

We have just started a field survey at a scallop farm in Same-no-ura, Ishinomaki City, Miyagi Prefecture, and it will take some time to get results yet.

Demonstration tests in Chiba Prefecture have confirmed that wakame seaweed can settle on the outside of upwelling pipes in winter.
If we estimate the economic effect based on the market price of this Wakame, it would be about 3,000 yen per Yusho pump.
If about 100 units were to be installed in a particular fishing port water area, an economic effect of about 300,000 yen per year could be expected.
It has also been shown that a variety of species such as juvenile shrimp, juvenile fish, and juvenile shellfish can live around the upwelling pump body and buoys.
However, the method of evaluation of the economic benefits they bring should be done through information exchange with researchers of fishery resources.
(2) Economic benefits in the field of disaster prevention and mitigation
Calculation of upwelling water volume due to installation of upwelling pumps:.
The upwelling calculation is not determined simply by the upward and downward motion of the pump, but must account for the amount of water that exits the pipe before the valve closes due to the upward acceleration of seawater in the pipe.
The following is a method for calculating the ideal upwelling rate.

$U = V\text{max} - \Delta\rho / \rho / gT = \pi H / T - \Delta\rho / \rho T$
$Q = AU = A \times \pi H / T - \Delta\rho / \rho \text{ x } gT$
*U: velocity of upwelling water, Vmax: maximum velocity, ρ: seawater density, g: gravitational acceleration, T: period, H: wave height

Assuming that the density of seawater is almost zero at a water temperature difference of 4° C between the top and bottom, the wave height H = 1 m, the period T = 6 sec, the inner diameter of the upwelling pipe 15 cm and the cross-sectional area A = 176 cm2 would be 9.2 liters/sec and the maximum upwelling would be about 800 m3/day.
The above calculations do not take into account the sinking loss of the buoys when the upwelling pipe rises, the resistance of the flowing water in the upwelling pipe, and the deflection loss of the tow rope due to resistance when the upwelling pipe descends.
If this upwelling water were spread evenly over the sea surface with a thickness of 10 cm, it would cool the sea surface temperature by 2° C during the typhoon season, with an area of about 8,000 m2.
If 100,000 wave upwelling pumps are installed in the shallow coastal areas, the sea surface

temperature of 800 km2, which is about 1/3 of the area of Tokyo, will be lowered by 2° C in just one day.
When it takes about three days for a typhoon to make landfall, a significant advance prevention effect can be expected.
And the cost of introducing such a system is expected to be about 30 billion yen.
Damage from the East Japan typhoon in 2019 was a record 1.88 trillion yen.
The cost-effectiveness is high enough compared to the amount of damage caused by typhoons (hurricanes and cyclones).

(iii) Economic benefits in the field of carbon pricing, such as reduction of CO
Basic research needs to be conducted to formulate a correlation between the amount of nutrient pumping in the lower layers and the amount of increase in marine plankton with respect to the CO_2 capture effect.
We believe that it is possible to evaluate CO_2 capture by marine phytoplankton by comparing the amount of chlorophyll in seawater in the upwelling pumped and un-pumped (target) areas.
Today, with the problem of reduced fish catches due to oligotrophic conditions in many parts of Japan, it may be important to take into account the equation relating nutrient concentrations by EC meters to planktonic growth.

(8) Direct and indirect effects of project implementation
<0.1% of the world's total catch in 0.1% of the world's waters reaches 50% of the world's total catch. > shows the potential of wave upwelling pumps to increase food supply, revitalize coastal fisheries, and create jobs and industries in this way.
So why has there been no research and development in this area to date?

As mentioned above, there are three possible reasons for this: licensing issues by the competent administrative agencies, the need for consent and mutual understanding among fishery stakeholders, and other issues on the part of the research implementers.

① The site is offshore, making risks, installation costs, and maintenance difficult.
② There are no evaluation criteria to calculate economic benefits.
(iii) Most researchers found that nutrients were present in deep water hundreds of meters below the surface, and not in coastal shallow-water areas a few meters deep.
*The existence of a fixed concept that deep water upwelling from a depth of 200-300m or more is essential.

However, the NPO ESCOT survey confirmed that nutrients, including iron, are present on the seafloor at depths of 2m to 4m, and that during summer days, the water temperature at 2m depth is 2-4° C lower than that at the surface.
The growth of marine phytoplankton is said to be governed by the iron element.
Many research institutes have found that iron, an essential element, settles and accumulates on the seafloor as iron oxide, and its weight prevents it from diffusing to the surface and being used for photosynthesis.
NPO ESCOT's wave upwelling pumps are also equipped with a function to agitate nutrient salts including iron deposited in low layers with a chain with a magnet hanging from the bottom of the upwelling pipe to the seafloor and diffuse them to the sea surface.

The size of the wave upwelling pump, which had been a hurdle to its introduction, was reduced to a DIY level.
As a result, a scallop farm in Miyagi Prefecture created and introduced a local youth club themselves.
This is one of the important results achieved since the start of this project.

Until now, there has been no energy-free check valve type wave upwelling pump for population upwelling in Japan.
Even overseas, most of them ended up at the thought-testing level or in data collection for a short period of time.
The development of equipment that could withstand long-term marine use, for which there are few precedents, was a continuous process of trial and error.

The lack of a series of examples caused unexpected problems.
Case Study.
*Spring pump was swept away with the buoy and recovered by a fishing boat.
Polycarbonate valve plates, which are supposed to be the strongest material, were damaged when the typhoon passed.
*Valve hinges break after an average of 20,000 to 30,000 open/close cycles per day.
*Rusting due to poor selection of stainless steel material

In this way, we repeatedly selected appropriate parts, put them into the field, and verified them.
However, such damage cases also had the effect of identifying areas for improvement, and

gave rise to new perspectives and ideas.

Case Study.
*Development of technology for bonding wind-receiving pipes to polyethylene buoys, which had been impossible for buoy manufacturers.
*Development of directional technology to direct the discharge of upwelling water at the sea surface in the downstream direction of the tidal current
*Development of technology to maintain the vertical posture of wave upwelling pipes in the sea and prevent shellfish from attaching to the inside of the pipes
*Development of technology to re-diffuse and upwelling of sedimentary nutrients on the seafloor as needed.
*Developed technology to prevent irregular vibration and rotation of wave upwelling pumps in rough weather
*Development of valve plug closing force generation technology covering the rubber wing and hinge on the side of the valve plate to improve the upwelling water volume during small waves.
We are still improving and accumulating knowledge.

Widespread dissemination of the knowledge gained to date will directly lead to the revitalization of marine ecosystems and CO2 capture through increased plankton, suppression of typhoon development through summer sea surface temperature cooling, and economic development and the creation of jobs and industries in the fisheries sector.

(9) Project Scalability and Reproducibility

We believe that the basic structure is simple and very easily understood.
In addition, almost all parts, with a few exceptions, are drainpipe materials, fishing gear, and ropes, so they can be procured in almost any country.
If parts are not available, we will supply them or help you find local substitutes.

The first stage of dissemination will begin with verification of the effectiveness of the reefs by DIY production and installation by the fishermen themselves, who have a direct stake in the project.
Therefore, manufacturing manuals will be provided initially.
Effectiveness against typhoons (hurricanes and cyclones) will be verified on a country-by-country basis after obtaining sea surface temperature data through implementation in the

fisheries sector.

NPO ESCOT is ready to offer online seminars and tutorials to disseminate its know-how.

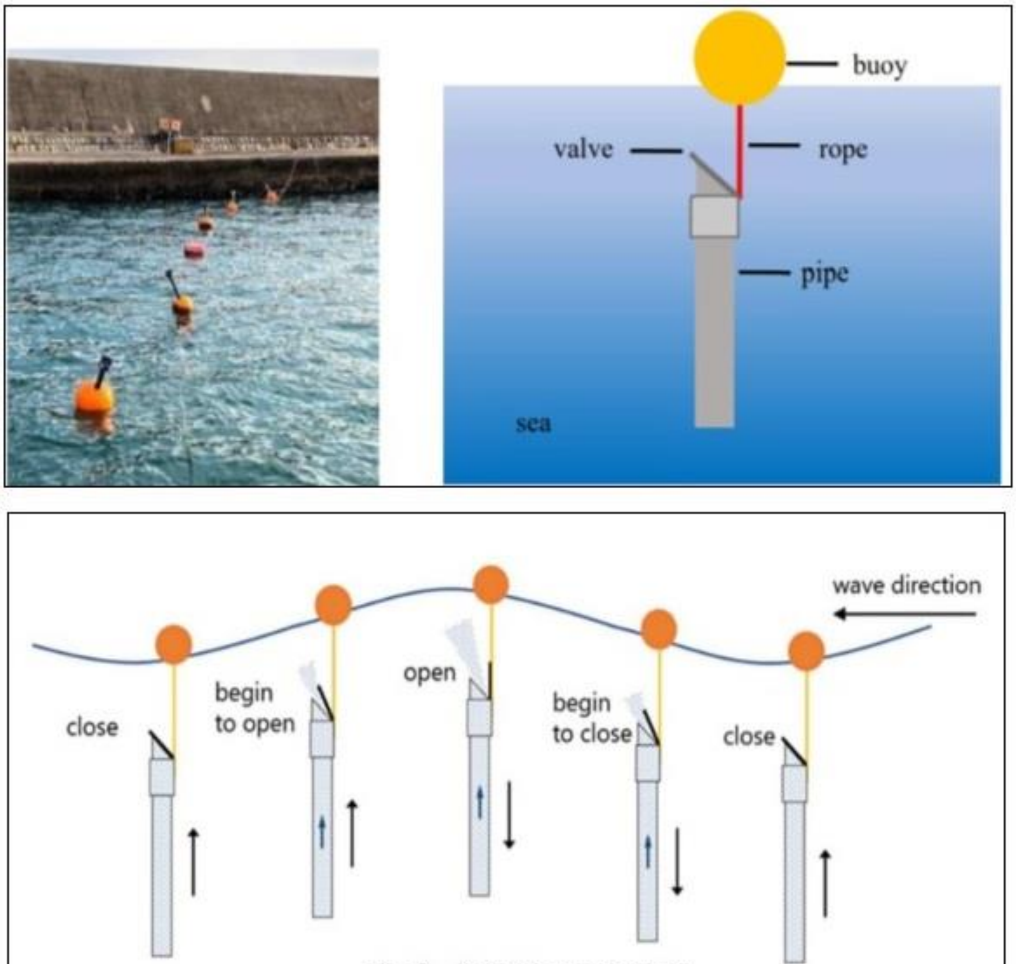
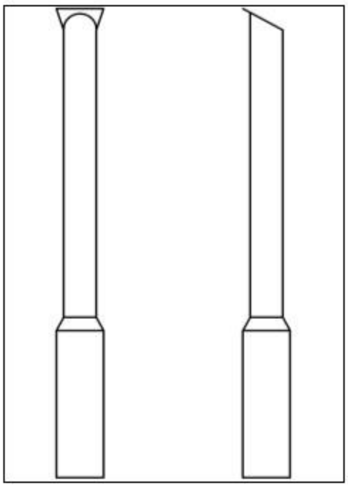
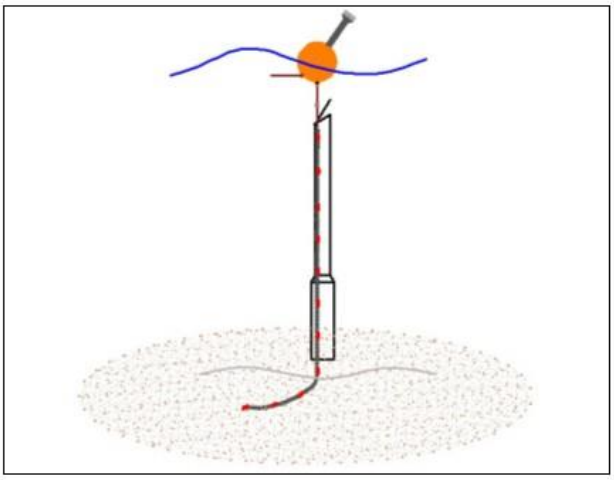


Fig.8 Working principle





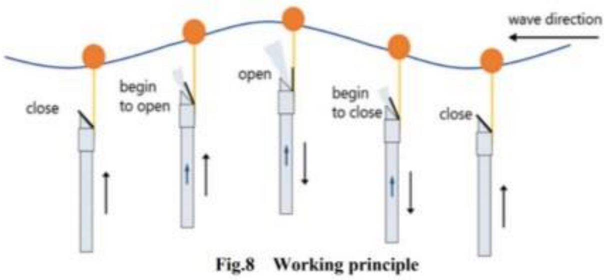


Fig.8 Working principle

Fig. 4 Conceptual diagram of "Takumi"





Experimental site in Onjuku fishing port
Chiba, Japan.
Wakame seaweed was found breeding
outside the upwelling pipe
and juvenile prawns were also observed.