POSSIBILITY OF RECYCLING LARGE-SCALE OBSOLETE VESSELS TO ENHANCE THE BIOLOGICAL PRODUCTIVITY IN THE JAPAN SEA NEAR HOKKAIDO

Masabumi SETO[1] and Tatsuaki SATO[2]

[1] Member of JSCE, Ph.D., Associate Professor, Dept. of Marine Bioscience, Hukui Prefectural University
(1-1,Gakuen, Obama, Fukui, 917-0003, Japan)
E-mail:setom@fpu.ac.jp
[2] M.Sc. Environmental Earth Science, Sect. of Environment Management, Alpha Hydraulic Engineering Consultants Co.,Ltd.
(9-14, Hassamu, Nishi-ku, Sapporo, Hokkaido, 063-0829,Japan)
E-mail:sato@ahec.jp

We explored the possibility of recycling large-scale obsolete vessels for upwelling deep sea water artificially to enhance the biological productivity in coastal areas. Large vessels as upwelling generator structures can create an extraordinary volume and height of upwelling flow, by far exceeding the capacity of conventional structures. Hulks also serve as grand-scale artificial fish reefs to preserve and nurture marine life. We estimated the impact of obsolete vessel structures on biological productivity, assuming such vessels are installed in the Japan Sea near Hokkaido. There are good prospects of recycled vessels being considerably more efficient than the hitherto-used structures, with their capability to help enlarge the developable sea areas as fishing grounds, as well as their usefulness in the creation of fishing grounds in deeper offshore waters.

Key Words: *Obsolete vessel , upwelling flow , deep ocean water*

1. INTRODUCTION

Recently, attempts at fertilization of coastal waters through artificial upwelling of high-nutrient deep sea water into the euphotic zone are being made in several regions of Japan, including Ehime, Nagasaki and Hokkaido. When the sea areas are fertilized by the implementation of artificial upwelling systems, the improved feeding environment will nurture rich living aquatic resources which otherwise will not prosper, but rather diminish at the earliest stage of development. Such efforts to sustain and increase resources through the stabilization of ecosystem should be positively encouraged as key projects in the fisheries-industry infrastructure building. The wall- and mound-type artificial upwelling structures have been developed, and are already undergoing at-sea experiments[1]. However, all those structures are installed within the depth range of around 50 to 80 m; too shallow to accomplish the direct upwelling of the deep water that is known to lie in a lower zone, for example, 150 to 200 m and deeper in the Japan Sea area. A new artificial upwelling technology, usable in deeper zones, is needed for the fertilization to be effective. In offshore areas, where new fishing grounds are expected to be developed, the systems must be of larger scale and capable of accurate evaluation of the effectiveness of development, since changes in submarine topography are milder than those in coastal areas.

The focus of this study is on the utilization of obsolete large merchant vessels, which are likely to have applicability to the deeper zones while meeting the requirement for larger-scale systems. A case study was conducted in the Japan Sea region of Hokkaido, where vessels were installed offshore to serve as man-made upwelling generator structures that would send up deep water directly. An evaluation was then made on the fertilizing effect of the resultant upwelling flows.

2. Recycled vessels - characteristics as artificial upwelling generator reefs

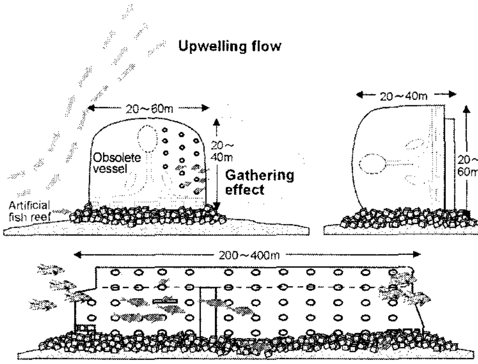

Fig.1 Conceptual rendering of an obsolete vessel utilized as an artificial upwelling structure.

Fig. 1 is a conceptual rendering of an large-scale obsolete vessel utilized as an artificial upwelling structure (hereafter called an "obsolete vessel structure"). We experimented on ships ranging from those with few superstructures such as tankers, full containers or bulk carriers, and with those whose entire mass consists of superstructures such as pure car carriers (PCC). In many cases the ship's cross section was almost rectangular, and for that reason, careful consideration had to be given to its upwelling efficiency, installation methods, and post-installation stability when deciding which part - the bottom, the upper deck or the flank - should be brought into contact with the sea floor. The following subsections discuss the characteristics of obsolete vessel structures.

(1) Applicability in creation of offshore fishing grounds

Obsolete vessel structures can measure by far larger in size than the conventional man-made upwelling structures in height and width (a few times each, making up a several times larger volume). They have potential for application in sea areas as deep as and deeper than 100 m, where it was hitherto considered difficult to create fishing grounds by means of man-made devices due to the limitations imposed by construction technique and cost effectiveness.

(2) A leap upward in upwelling efficiency

Obsolete vessel structures will allow the high-nutrient waters to come upwelling directly from the deep layer, thus effecting a significant increase in the ratio of biological productivity to upwelling flow volume by comparison with any existing systems.

(3) Ecosystem-based structures

Obsolete vessel structures for artificial upwelling will provide a means for improving the basic food environment

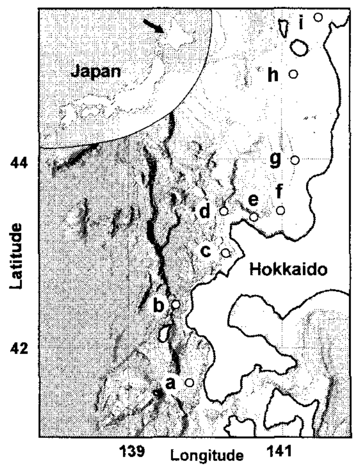

Fig.2 Location map of the investigated area of the Hokkaido Japan Sea. [a] to [i] indicate the observation points for nutrient data analysis.

which depends on the amount of primary production. They will also function like vast man-made fish reefs as a part of an ecosystem-based fishery environment. Not only feeding grounds but also hiding places will be provided for the plankton-eating fishes that consume the primary foods produced by upwelling flows, as well as nurseries for the higher-level predators.

(4)Economical efficiency

Through the effective recycling of used ships, obsolete vessel structures will much improve the business efficiency with respect to size of installed systems by comparison with their existing counterparts. It would promise an even higher level of cost effectiveness when the figures of upwelling efficiency are allowed into consideration.

(5)Consistency with the recycling-oriented society

When utilizing abandoned structures and industrial wastes as obsolete vessel structures, the process involves less resource energy consumption and can be implemented in shorter work periods for assembly and installation than are required by the construction plan for new systems.

3. Applicability in the Hokkaido Japan Sea area

(1) Hydrographic structure and biological productivity in the Hokkaido Japan Sea area

To clarify the oceanographic characteristics of this particular sea area, assessments were made using the published

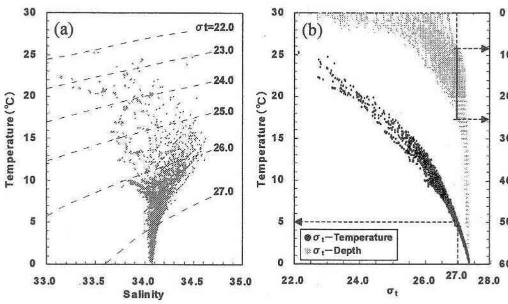

Fig.3 (a) is the temperature-salinity diagram for the point [a]. (b) shows the changes in temperature and salinity as functions of sigma-t, based on the data from 3(a).

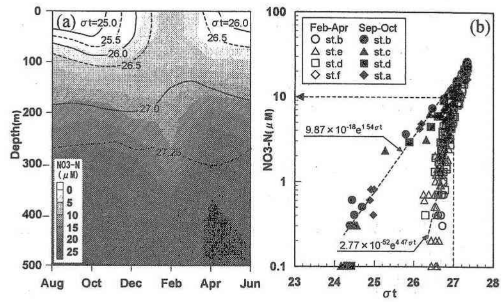

Fig.4 (a) shows the cross-sectional distribution of seasonal changes in nitrate concentration at the point [d]. (b) is a plot of nitrate concentration at points [a] to [f] in Figure 2 as a function of sigma-t, for spring (February through April) and for autumn (September through October).

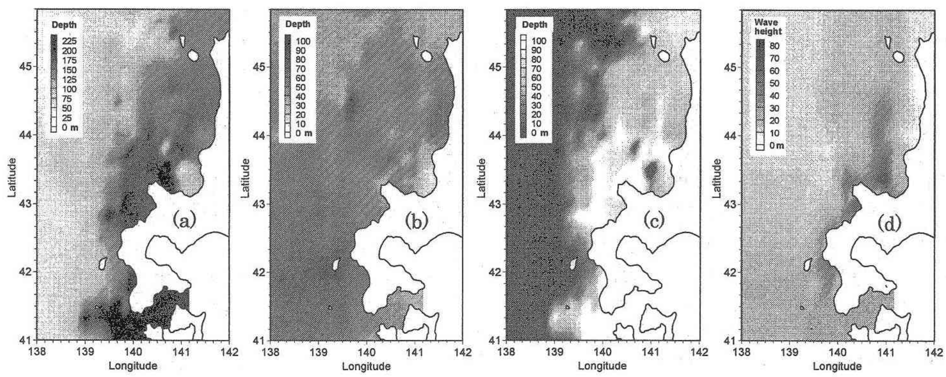

Fig.5 Two-dimensional distributions of formation depth of 27.0-σt isopycnic surface (a), formation depth of 1% compensation depth (b), required upwelling height(c), and internal wave height (d) in the Hokkaido Japan Sea in September.

data from Hokkaido Fisheries Experimental Station and the Japan Oceanographic Data Center (JODC). The data included the information about each layer of the area, collected over the past 20 years. We prepared a chart with 10-minute (latitude and longitude) meshes, and replotted the values of water temperature, salinity and transparency. Figures for each of the data elements were averaged by mesh and by month, and then were used to calculate concentration and other relevant values. Since the data on nutrients were too scarce in number to begin with, we could not treat them in the same way as temperature or salinity. For nutrients, only the eight observation points as shown in **Fig. 2** ([a] to [i]) were available.**Fig. 3(a)** shows the T-S (temperature-salinity) diagram plotted from the data for virtually every month obtained at the point [a] of **Fig. 2**. **Fig. 3(b)**, which is based on the data from **Fig. 3(a)**, shows the changes in temperature and salinity as functions of σt (sigma-t), indicating that the formation of a seasonal pycnocline occurs when the sigma-t value is around 27.0, and that the sea water density depends significantly on water temperature in shallower zones above 27.0 σt. It also indicates that the formation depth of the 27.0-σt isopycnic surface varies greatly with the seasons over a range as wide as 85 to 255 m. The observation data for nitrates, obtained at the point [d] of **Fig. 2**, were also averaged by month, and were used to graph out the seasonal change in cross-sectional distribution of nitrate concentration as shown in **Fig. 4(a)**. The resultant graph shows that the nitrate concentration varies significantly with the flux and reflux of the warm Tsushima Current, if the water is shallower than 27.0 σt. Around September each year, when the Current's flow volume becomes maximum, the nitrate concentration lowers to the minimum level. From the end of October the weakening of pycnoclines promotes the vertical mixing, and the mixing reaches at its peak around February. **Fig. 4(b)** is a plot of nitrate concentration at each point in **Fig. 2** as a function of sigma-t, for autumn (September through October) when the pycnoclines become most developed, and for spring (February through April) when the vertical mixing is most prominent. Where sigma-t is over 27.0, the ratio of nitrate concentration to the sigma-t value is almost fixed, regardless of seasons or of observation points. At 27.0 sigma-t, the nitrate concentration value lies around 10.0 almost all year round. The same is true for other important nutrients, the figure being 1.0 μM for phosphates and 15.0 μM for silicates, both at 27.0 sigma-t. We chose the formation depth of the 27.0-σt isopycnic surface as the reference point in our research on deep-water dynamics in the Hokkaido Japan Sea area.

Fig. 5(a) is the 2-D distribution chart of Hokkaido Japan Sea area showing in what depth the 27.0- σt isopycnic surface is formed in September, the month the warm Tshushima Current flows at the full rate. The monthly change in the 27.0-σt isopycnic surface formation depth is in close correlation with the flow rates of the warm Tshugaru Current and its northward branch, the Tsushima Current. When the northward flow reaches its annual peak in September, the 27.0-σt isopycnic surface lies deeper than in any other months, although it would lie extremely shallow at some points near the Okushiri Island and around the mouth of the Ishikari Bay.

Fig. 5(b) is the 2-D distribution chart showing in what depth the 1% compensation depth lies in September, based on the transparency data of Hokkaido Japan Sea area. As a rule, the compensation depth becomes minimum in April, the high season of primary production, and becomes maximum from September to October, when the influence of warm Tshushima Current is strongest. In the innermost recesses of the Ishikari Bay, by comparison with the other areas, transparency remains lower and changes only within a narrow range, due to its vulnerability to the riverine effects via coastal waters.

Light is essential for the propagation of phytoplankton, and compensation depth as shown in **Fig. 5(b)** is a determining factor for light intensity. On the other hand, the reference depth for nutrients is determined by the formation depth of the 27.0-σt isopycnic surface as shown in **Fig. 5(a)**. **Fig. 5(c)** shows the Hokkaido Japan Sea region in September, representing the 2-D distribution of required upwelling height, which is defined as the difference between the compensation depth and the 27.0-σ isopycnic surface formation depth. Actually, even where the required upwelling height is visible on the chart, the position of isopycnic surfaces may shift vertically or the pycnoclines may be broken temporarily, under the influence of migrating low pressures or that of shear flows between the upper and lower adjacent layers[2]. This admitted, the chart can safely be assumed to provide a reliable reference for the 2-D distributional characteristics of the area's primary productivity, considering that the smaller the required upwelling height, the larger the mass of nutrients transferred from the depth upward past the isopycnic surface through such natural phenomena. Around the Okushiri Island as well as in the entrance area of the Ishikari Bay, the values of required upwelling height become notably small in summer, with the warm Tsushima Current at its peak of force, while the overall nutrient concentrations remain at a low level from early summer through autumn. Thus the smallness of required upwelling height characterizes these particular points as prospective grounds for artificial upwelling projects.

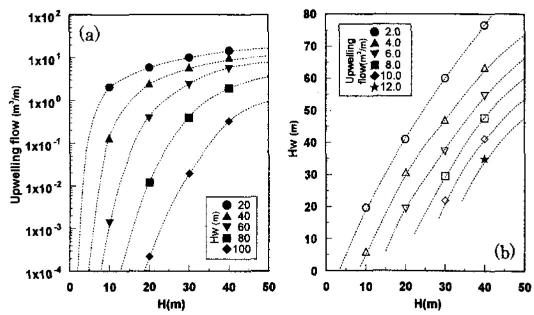

Fig.6 Changes in upwelling flow volume and upwelling height are shown in (a) and (b), respectively, as functions of the height (H) of an obsolete vessel structure.

(2) Potential of obsolete vessel structures for increasing primary productivity

In order to predict the upwelling effects of obsolete vessel structures in the Hokkaido Japan Sea area, the structures' upwelling efficiency must be calculated in advance. Regarding the upwelling characteristics of artificial upwelling structures, data by Incorporated Association Marino Forum 21 are available, including the results of hydraulic model experiments with various types of structures. In their research, for example, dye (modeling nutrient) was put into the bottom layer to evaluate how the concentration changes as a function of the bottom water's upwelling height[4]. None of their data directly dealt with the similar shape and construction as the obsolete vessel structures we are proposing, but, since the cross-sectional view of obsolete vessels presents the combined features of the wall type and the mound type, we considered the upwelling characteristics of obsolete vessel structures to be represented by the intermediate values between the wall and the mound type.

The two graphs in **Fig. 6** outline the incremental characteristics of upwelling flow volume and upwelling height (HW), respectively, as functions of the height of an obsolete vessel structure (H). The flow velocity of the bottom-layer mainstream is assumed to be 0.4 m/s. According to the graphs, if the structure's height is the same, upwelling height and attained depth are inversely proportional to each other. They also show that while both the volume and height of upwelling flow increase with the structure's height, the in-

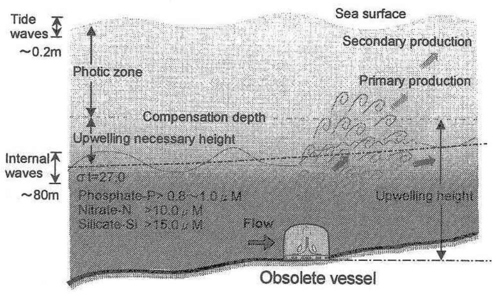

Fig.7 Upwelling generator model using an obsolete vessel in the Hokkaido Japan Sea area where internal waves are dominant.

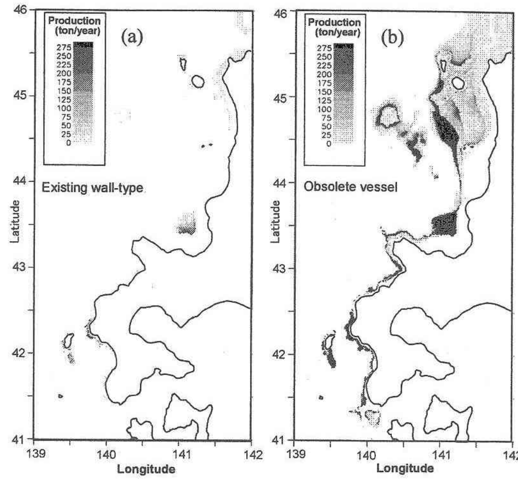

Fig.8 Expected annual increase in biological production in the Hokkaido Japan Sea area, supposing artificial upwelling structures are installed. (a) for the existing wall-type (height 10 m, width 45 m) . (b) for the obsolete-vessel type (height, 30 m, width 200 m).

creasing rate of attained depth as a function of the structure's height depends almost solely on the shape of the structure and remains nearly fixed, regardless of flow volume. Although the current velocity in the bottom layer is fixed at 0.4 m/s for the purpose of **Fig. 6**, it was also recognized that the higher the structure, the greater the ratio of increase in upwelling flow volume to increase in the bottom-layer current velocity.

Fig. 7 presents a conceptual drawing of the upwelling model by an obsolete vessel structure in the Hokkaido Japan Sea area. Tidal range is characteristically small in the Japan Sea, so we can hardly draw on tidal energy. Instead, we focused our research on the availability of internal wave energy, as a usable type of natural energy, in upwelling deep-water nutrients constantly past the pycnocline and into the upper zones. Internal wave energy, in this particular region, gathers from early summer to autumn and is in proportion to the development of pycnoclines. This energy is known here to equal or even surpasses tidal energy in terms of amount, and, to become most dominant in summer when nutrient concentrations drop significantly as clarified by the hydraulic model experiments, modeling the Japan Sea, as well as, through the oceanographic observations[3]. The estimated distribution of internal wave energy in terms of wave height is shown in **Fig. 5(d)**[3]. The wave height is relatively taller in coastal waters and becomes shorter through attenuation in offshore areas. Apart from the regional energy concentration observed inside the Iwanai Bay to the west of the Shakotan Peninsular, the greater part of internal wave energy runs northward and follows the contour of the Peninsular, entering the Ishikari Bay to form an energy concentration along the Bay's entrance. At a few points in these bay areas, the maximum wave height is estimated to reach as high as about 80 m.

Following, is the method for calculating the values of the transferred nutrient flux in order to know how much nutrient will be transferred into the zones above the compensation depth by the use of obsolete vessel structures. First, the vertical distribution of nutrient concentrations is worked out from the values of 27.0-σt isopycnic surface formation depth given by **Fig. 5(a)**. The horizontal flow velocity generated at the installation depth is given by reference to the internal wave conditions as shown in **Fig. 5(d)**, and then, in turn, is utilized to calculate the upwelling flow volume, which is a function of horizontal flow velocity and height of the structure, as plotted in **Fig. 6**. Lastly, the amount of transferred nutrients is calculated from the values of upwelling flow volume and deep-water nutrient concentrations at the installation depth, by reference to **Fig. 5(b)** and **Fig. 5(c)**.

The next step is to estimate the amount of primary production and final biological production. This is done by utilizing the data on transferred nutrient flux given above, and, by using nitrogen as an indicator. In this research, we adopted the typical C/N atomic weight ratio for phytoplankton (=4.3) to calculate the net primary carbon production yielded by the upwelling flow. The estimation of primary production that is phytoplankton production was based on an approximate figure (20.0) obtained from the amount of carbon and the live weight of phytoplankton[5]. As the conversion efficiency from primary production to each higher trophic level, 0.15 (the figure for coastal areas) was applied for both the plankton and the benthic ecosystems. The energy transfer efficiency from primary production (plankton ecosystem) to the benthic ecosystem was estimated as 30%. Evaluation was made for two-leveled and

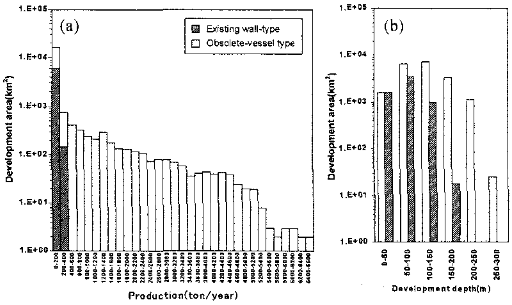

Fig.9 Correlation of the expected range of developable area to the expected increase in annual biological production (a), and to the installed depth (b) in the Hokkaido Japan Sea area supposing artificial upwelling structures are installed.

three-leveled trophic structures, assuming that they exist fifth-fifty in both the plankton and the benthic ecosystems [6),7),8)].

Fig. 8 presents the distribution charts of expected annual increase in biological production, supposing two different types of artificial upwelling generator structures are installed in the Hokkaido Japan Sea coastal regions. Estimation was made for the wall-type (wall height 10 m, installed width 45 m) and the obsolete-vessel type (height 30 m, width 200 m), based on the 1-km mesh depth data. **Fig. 9(a)** shows the correlation between the expected annual increase by area and the expected range of productive waters (regions developable as fishing grounds), with respect to each structure type. The graph in **Fig. 9(b)** shows correlation between the installation depth of artificial upwelling generator reefs and the expected range of developable waters.

This data points to the advantages of artificial upwelling reef systems by obsolete vessels over the conventional wall-type structures, in that the vessel-type has potential not only to increase biological production by about 60 times but also to extend the installable and developable sea area even to the depth of 200 m and deeper, a depth where the existing systems could hardly be efficient.

4. Conclusion

There are issues that still need to be resolved, such as the correlation of ship's shape or placement with upwelling efficiency, estimation of post-installation stability and durable years, or new sinking techniques to take full advantage of ship's characteristics. The development of obsolete vessel structures - the reutilizing of the biggest construction man ever created - is a highly prospective means of realizing the recycling-oriented society through effective use of limited resource energy, as well as, exploiting the immense offshore regions for human activities worthy of remark and expectations.

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大型廃船をリサイクルした北海道日本海の肥沃化に関する基礎的研究

瀬戸雅文・佐藤達明

海洋深層水を人工的に湧昇させて沿岸域の生物生産を増大させるための構造物として、大型廃船の再利用の可能性について検討した．その結果、大型廃船は、従来の人工湧昇流発生構造物と比較して、発生する湧昇流の流量と海洋深層水の湧昇高さを飛躍的に増大できる可能性が示唆された。大型廃船を北海道日本海に設置した場合の生物生産効果について検討した結果、大型廃船は、従来の構造物と比較して漁場の開発が可能な海域面積を大幅に拡大させるとともに、更に深い沖合漁場の開発にも有効であることが明らかとなった。