The Nippon Foundation

Final report on the comprehensive management against biofouling to minimize risks on marine environment

October 2010

Ocean Policy Research Foundation
(Ship & Ocean Foundation)

Table of contents

1. Biofouling by alien marine species and biofouling organisms

1.0.1 This chapter describes the mechanisms of transfer and invasion of marine species associated with ship biofouling, a major factor causing biofouling by alien marine species, and key points involved in the control of biofouling organisms in order to prevent biofouling-related damage. In this chapter, the term “alien marine species” is used to define those marine species that are transferred by human activities from their original habitat and then settle in another country’s waters. The term “bioinvasion” is used to define the effects of and dangers posed by these marine species to humans, plants and animals, economic and social activities, and to the marine environment.

1.0.2 In Japan, even before the transfer and settlement of alien marine species was recognized as a serious problem, native marine species were already being distributed throughout local waters and having an effect on the environment and causing damage. Extensive development of Japan’s coastline from the end of the World War II until 1990, and much attention was focused on the attachment of marine organisms. For example, in thermal and nuclear power plants that required large amounts of seawater as coolant, a large number of marine organisms becoming attached to coolant pipes or heat exchangers could lead to a reduction in cooling and heat exchange efficiencies. In the worst case, this could even result in plant shutdown. There were two possible reasons for the emergence of this problem: [1] intensive land reclamation and the expansion of port facilities, and [2] eutrophication in nearshore waters as a result of economic development. The former increased the amount of damage by expanding the extent of artificially protected coastline which then provided suitable habitats for the attachment of marine organisms, and the latter induced competition and selection between native species, facilitating the growth of marine organisms with the ability to adapt to extreme environmental changes. These issues occurred not only in Japan but also in other countries where industrial facilities were established in coastal areas.

1.0.3 International maritime trade was also developing at this time and vessels such as oilers and high-speed container vessels were brought into use. Consequently, not only in Japan but also in every other country with similarly advanced maritime development, the chances of transfer and emigration of alien marine species increased. As a result of the increase in both the number of industrial facilities vulnerable to colonization by attached organisms and the frequency of translocation of alien marine species, environmental effects and damage caused by both native and alien marine species emerged as a worldwide problem.

1.0.4 The effects and environmental damage caused by alien marine species are common problems in coastal countries and almost all of these countries are similarly at risk. Many cases of damage have been reported around the world with the United States, for example, estimating 2.4 billion dollars per year (approximately 216 billion yen) in damage. If this state of affairs is left uncontrolled, not only environmental damage, including biodiversity loss, but also social and economic damage to industries in coastal areas and fisheries may increase. The International Maritime Organization (IMO) has already noted the effects and environmental damage caused by biofouling of alien marine species and has recognized the necessity for countermeasures and is currently actively engaged in discussions on how best to address these issues (see Chapter 2).

1.0.5 Marine periphyton communities, when growing on a solid surface (attached base) with an area of several cm^2 or more in water, such as the outer hull skin on ships, seawater intake pipes and water-soaked surfaces on offshore structures, initially form a coating of unicellular microorganisms (called micro biofouling) during the first phase of their development. Next, in the second phase of development, multicellular organisms such as seaweed and barnacles attach themselves to this coating (macro biofouling) and communities start to grow.

1.0.6 Micro biofouling means a phase of a hull surface when it is coated with [1] microscopic unicellular protists such as bacteria and diatoms, and [2] microorganisms covered in slime substances (usually extracellular polysaccharides) generated by unicellular protists and the slime layer generated by these organisms. After micro biofouling is established, immobile multicellular communities including seaweed, *Serpulidae*, barnacles and ascidians develop on the micro biofouling, leading to the establishment of mobile multicellular communities including organisms such as the common mussel, attaching themselves by means of byssus threads, i.e., the macro biofouling phase. This macro biofouling generally causes environmental damage and has substantial effects on industries in coastal areas and fisheries.

1.0.7 Macro biofouling forms in three-dimensional space and grows increasingly complex over time, allowing plants and animals that cannot normally attach themselves to a ship's hull (called hitchhikers), e.g., shrimps, crabs, *Gammaridea*, *Caprellidea* and conchs, to also inhabit this space as well. Invasion by organisms that are not naturally periphytic has been found around the world and it is possible that many of these organisms were translocated by attaching themselves to ship hulls by means of the above process.

1.0.8 Based on the ecological characteristics of the alien marine species described above, several marine species were selected that were likely to be transferred from the seas surrounding Japan into the seas of other countries and cause environmental damage and other adverse effects. The selection procedures applied in this report were as follows: a comparison was made of the optimal survival conditions (including water temperature and salt concentration) for species living in seas surrounding Japan with the environmental conditions of a typical foreign port, and those species whose optimal survival conditions were similar to the environmental conditions of the foreign port were considered potential invaders. Subsequently, past cases of damage caused by each of these potentially invasive species were evaluated and those species with higher incidences/larger potential for damage and that could have the greatest effect on the society, economy and coastal ecosystems were identified. Consequently, 13 species including immobile organisms such as seaweed, *Serpulidae*, barnacles, ascidians and clams (with a strong byssus attachment) were selected as species that had the potential for invasion and were likely to have a significant effect and cause environmental damage.

1.0.9 In this survey, these 13 species were considered as typical organisms with high invasive risk and their ecological characteristics and mechanisms of transfer/invasion were investigated. Based on the above results, an approach for controlling these organisms was then developed. While adults of these 13 selected species live fixed in place by means of an attached base, earlier in their lifecycle they are free-floating in water. The length of this floating phase ranges from several days to 2 months after their release from sexually mature individuals as an egg or a gametophyte. Following the floating phase, these organisms grow and proceed to the attachment phase, affixing themselves to a solid base such as a ship's hull. After attachment, these organisms then complete their remaining lifecycle fixed in place. Based on these ecological characteristics, the major mechanism of attachment and invasion by alien species is considered to comprise the following processes. [1] Immobile marine organisms near a port spawn eggs or spores and floating larvae which are distributed throughout the port area. [2] Floating larvae attach themselves to the outer hull of a ship moored in the port. [3] These organisms grow and become sexually mature while attached to the ship's hull. [4] Sexually mature organisms produce eggs or spores in foreign areas with the appropriate conditions for spawning. [5] If the marine environment into which the eggs or spores are delivered is appropriate for the organisms, eggs hatch and larvae attach themselves to a firm base. [6] Larvae grow, become sexually mature and produce the next generation of eggs or spores, leading to the successful colonization and settlement of these organisms in a foreign sea. Therefore, to prevent the adverse effects and damage caused by the transfer and settlement of alien marine species in this manner, it is important to prevent their attachment to ship hulls, as in described in [2], and deprive the species of the opportunity to spawn, as described in [4], as much as possible. The anti-fouling coating system (AFCS, see Chapter 3), the most popular self-polishing antifouling paint, is already used as a countermeasure to prevent the attachment of organisms to ship hulls, as described in [2]. However, ship cleaning in a dock, the most effective countermeasure available to deprive organisms of the opportunity to spawn, as described in [4], greatly affects ship's activities, therefore, very difficult to increase the frequency of cleaning without further disruption. Thus, in order to minimize the opportunities for hatching [4], it is important to visually confirm whether or not organisms have attached themselves to the outer hull while the ship is underway and to also collect these organisms when cleaning the ship at sea, as well as in dock.

1.0.10 The size of the biofouling organisms is an important consideration when deciding which of the above procedures to use to control them. In this survey, the minimum size of sexually mature individual organisms and the minimum size of plants and animals in the early attachment phase were investigated. For example, to remove biofouling organisms, it was estimated that it would be necessary to collect attached materials smaller than 1 mm in size, considering the need for a suitable safety factor. However, the life cycle and the minimum size of organisms including seaweed gametes to collect for the prevention of any organism is not yet well understood, biologically. Therefore, it is currently difficult to estimate which species need to be monitored and detected, and the minimum size of the organism for which inspection and collection should be carried out. Thus, it was concluded that practical and effective measures for the comprehensive control of biofouling organisms should be developed based on the technical limitations of devices and products likely to be used in control systems in the future (e.g., the net size of devices used to collect organisms, the physical size or organisms to include in detection tests, etc.), rather than on any biological considerations.

2. The trends emerging from discussions carried out by the International Maritime Organization (IMO) concerning the prevention of invasive alien aquatic species

2.0.1 The International Maritime Organization (IMO) is currently developing draft "Guidelines for Minimizing the Transfer of Invasive Aquatic Species Through Biofouling of Ships ". This chapter outlines the background to the development of these guidelines, the current draft guidelines, the contents of discussions held by the IMO, and each nation's attitude to the proposed regulations.

2.0.2 The IMO first recognized the mechanism involved in the unintentional transfer of organisms associated with ocean freight and adopted the International Convention on the Control of Harmful Anti-fouling Systems on Ships (the AFS Convention) in 2001. After that, a full-fledged discussion was held on this issue in order to establish regulations for ships' ballast water. With regard to the problem of ballast water, the assembly of the IMO adopted the "Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens" in 1997 and, in 2004, adopted an even stricter regulation, the "International Convention for the Control and Management of Ships' Ballast Water and Sediments" (the Ballast Water Management Convention). However, since many nations have still not ratified the Ballast Water Management Convention in 2010, 6 years after the convention was established, this convention has not yet come into force. The lack of ratification has caused much concern over the increasing risks of invasion of alien species in water areas in those nations that are promoting ecosystem protection measures. The confirmation that alien species were likely to be transferred through biofouling of ships added to these concerns. Consequently, Australia considered it necessary to start discussions concerning regulation as soon as possible and raised issues related to the transfer of organisms through biofouling of ships.

2.0.3 The 54th meeting of the Marine Environment Protection Committee (MEPC) of the IMO, which was held in March 2006, initiated the discussion of issues related to the invasion of alien species through biofouling of ships. The Australian government carried out a survey in 1999 and reported that 77% of alien marine species transferring into Australian waters did so through biofouling of ships and that this means of transfer was more significant than that occurring through ships’ ballast water, which was already covered by the convention. Furthermore, the Australian government then sought advice on control measures from other nations. Therefore, the MEPC requested that other nations also provide similar information. The Australian report and request marked the start of discussions on regulation by the IMO.

2.0.4 The 56th MEPC meeting agreed that the top priority on the agenda for the 12th session of the Sub-Committee on Bulk Liquid and Gas (BLG) should be the "Development of international measures for minimizing the transfer of invasive aquatic species through biofouling of ships”. As a result, a full-fledged discussion of this issue was conducted. The 12th BLG session in February 2008 established the "Correspondence group for discussion of issues related to the development of international measures for minimizing the transfer of invasive aquatic species through biofouling of ships". Furthermore, the 13th BLG session in February 2009 reestablished the correspondence group and decided to develop draft "Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species" before the 14th BLG session.

2.0.5 The 14th BLG session in February 2010 established the Working Group and, based on the draft guidelines proposed by the correspondence group, a full discussion was then conducted. Consequently, the contents of the guidelines were nearly finalized. However, because the guidelines are voluntary basis, the Japanese government proposed to delete the obligatory expressions and contents in the text and revise the contents into feasible measures that could be supported by as many nations as possible.
The correspondence group, which was reestablished in readiness for the 15th BLG session to be held in February 2011, approved continued development of the guidelines and the establishment of the Working Group in the 15th BLG session in order to finalize the guidelines by 2011 and adapt them as early as possible. The guidelines that the IMO is developing will be voluntary and have no power to force ship owners, shipyards and shipping agents to comply. However, enforceable regulations often adopt the same framework and thresholds proposed by voluntary guidelines, as shown in the process used to establish the Ballast Water Management Convention. In this research project, we therefore considered the above proposals in detail and sought to contribute to the development of future guidelines which could be used in international frameworks.

2.0.6 This chapter outlines the attitudes of various nations to the regulations, focusing on the contents of discussions held in the IMO. Maritime nations, including Japan, have basically opposed any regulations that could have a significant effect on shipping and increase costs. However, it is considered that these maritime nations should still accept the regulatory measures as long as they do not have an excessive effect on the current shipping system, considering the risks already posed by bio-invasion. Among the list of nations requesting regulatory measures, Australia, which first raised the issue of transfer of organisms through biofouling of ships, considers that more attention should be paid to the regulations. The Australian government probably plans to introduce strong regulations in the near future. In addition, they consider it necessary to assess the extent of organism invasion associated with in-water cleaning (IWC: physical removal of attached organisms from outer hulls in water) and the chemical risks posed to the environment (effects of the residual toxicity of active substance in the coastal ecosystems), based on scientific evidence. Therefore, they have requested that the results of these risk assessments be reflected in the framework of the above guidelines. On the other hand, there is no internationally accepted, reliable, standard assessment model, study method or tool for the assessment use at present. We believe that the chemical and biological risk model for transfer of organisms that we have developed in this project (Chapters 5 and 6) is a set of promising tools to base the framework of future regulations on. The U.S. government thinks that IWC implementation is an issue that each nation should determine for itself, after considering all chemical risks to the environment. Furthermore, they consider it appropriate to determine the need for IWC by in-water inspection after a certain period of time from docking or after the last IWC treatment because IWC timing depends on the leaching rate of antifouling paint. Many European nations agree with the U.S. position on IWC.

3. The current status of and possible future improvement of efficacy of AFS and other antifouling devices

3.0.1 An anti-fouling system (AFS) is defined as a device/treatment used to prevent or control biofouling of ship hulls. The definitive aims of AFS are [1] antifouling: to prevent or inhibit biofouling itself, and [2] biofouling removal: to restore ship performance [1] by scraping off fouling organisms. In this chapter, AFS devices used for [1] are evaluated in terms of their performance, risk, cost and potential for future improvement.

3.0.2 With regard to the devices used for antifouling, it is easiest to understand their performance by considering their different application sites on ships, i.e., the anti-fouling coating system (AFCS, typified by antifouling paint) used for outer hull painting, and the marine growth prevention system (MGPS) used for more complex ship parts except outer hull skin. The most widely used and very effective AFCS involves the use of self-polishing antifouling paints containing compounds that prevent biofouling (biocides). The seawater electrolysis system, a common MPGS, is another major antifouling device as well as AFCS. In this chapter, leading antifouling devices such as the self-polishing antifouling paint and seawater electrolysis system are evaluated in terms of their operating mechanism, performance and cost, respectively. In addition, other devices that may be included in future antifouling control systems are also examined.

3.0.3 The principle of the self-polishing antifouling paint, a leading antifouling device, involves the painted surface contacting seawater and hydrolyzing and leaching antifouling components containing active substances which have a short-term ecological effect (e.g. repellent effects) on organisms and prevent biofouling. A high performance self-polishing antifouling paint containing organotin as an active substance was widely used in the past. However, its production and use are currently banned due to high toxicity and bioaccumulation. The antifouling effect of any self-polishing antifouling paint targets nonspecific organisms and both the outer hull skin and various other ship parts are usually coated with the same antifouling paint. The antifouling painted surface is renewed at specific intervals, depending on its properties, and provides stable, long-term antifouling performance. Most self-polishing antifouling paints contain active substances such as copper (I) oxide, pyrithione zinc and pyrithione copper.

3.0.4 Many of self-polishing antifouling paints manufactured by Japanese paint companies have an antifouling performance that lasts for approximately 3 or 5 years before needing renewal in dock. The method used in Japan to test antifouling performance and evaluate the persistence of the antifouling effect is conducted in accordance with the following procedures: a test plate coated with a self-polishing antifouling paint is soaked in seawater and the state of organism attachment to the plate is observed. However, the kind of test plate used, the soaking process and duration of soaking, the target organism and the observation standards differ between examiners and have not yet been standardized. The performance of antifouling paints is evaluated using different test methods by companies in other countries as well as Japan. Consequently, many ships are re-painted with antifouling paint at shorter intervals than those for which the persistence of antifouling performance has actually been verified.

3.0.5 The performance of antifouling paint is the main component of antifouling control system, therefore, it is essential to establish internationally standardized test methods for performance evaluation. The most appropriate method is to establish an artificial system involving optimal conditions for organisms to attach and then to conduct a performance test under the same conditions. However, this is expensive and it takes a lot of time and effort to adjust and integrate the test conditions. In consideration of the above issues, the performance test needs to be standardized using the following processes: comparing an unpainted plate and a test plate coated with paint with a known performance with an antifouling painted-plate and balancing out the differences in test sites and conditions by normalizing the area covered. It would be desirable to indirectly promote the use of high-performance antifouling paints by developing the above performance test as soon as possible and proposing its use to the International Paint and Printing Ink Council (IPPIC) through the Japan Paint Manufacturers Association.

3.0.6 Through surveys carried out among Japanese antifouling paint manufacturers, it was confirmed that biofouling organisms on the wetted surface area of hull, bilge keels, thruster tunnels and sea chests are always found and removed in dock, even after intervals of as little as 2.5 years. This result suggests that some organisms are found attached to all ships whenever they dock. Since the condition of the ships figured out by the survey are considered to be “average” for self-polishing antifouling painted ships in Japan, this suggests that, in practice, the antifouling performance of self-polishing antifouling paint is less than the 3 years specified by Japanese antifouling paint manufacturers, i.e., antifouling paint performance does not actually extend for the designed time period. Based on the results of this survey, the cost of self-polishing antifouling paint per ship varies in accordance with ship size and ranges from 10 million to 100 million yen.

3.0.7 Advanced products which have stronger inhibitory effects on organism attachment than the current self-polishing antifouling paints are also becoming available in the market. These products exhibit improved performance in terms of the type, content (%) and leaching rate of their active substances and, consequently, the antifouling performance of these products is higher than that of conventional products. It is also known that silicone-containing antifouling paint has a high antifouling performance. These novel antifouling paints are expected to be introduced more widely in the future. However, the cost of novel AFCS products is estimated to be 2 to 5 times higher than current popular self-polishing antifouling paints. Therefore, the cost of coating an entire ship may exceed 100 million yen. While the coating cost depends on future use and may decrease over time, these new products are not a realistic alternative at present.

3.0.8 It would be desirable to reduce the cost of novel high-performance antifouling paints. However, we propose another approach for reducing the amount of biofouling on ships without an excessive increase in cost, i.e., applying different antifouling paints to different parts of the ship. For example, a sea chest on which biofouling is severe can be coated with a high-performance antifouling paint containing large amounts of active substances with high ecotoxicity or with an antifouling paint with a high leaching rate of its active substances while other parts of the ship are treated with less expensive products. The application of an expensive antifouling paint to only some parts of the ship prevents any substantial increase in cost because the relative area coated with the expensive antifouling paint is small. Even if an antifouling paint containing active substances with high ecotoxicity or a high leaching rate is used, the risk posed by the active substance to environmental organisms would not substantially increase because the application area is much smaller than the overall surface area of the outer hull skin.

3.0.9 The seawater electrolysis system has already been used in practice as a leading antifouling device for the inner piping of cooling water systems where it is difficult to apply an antifouling painting. The seawater electrolysis system is a device designed to protect the pipe walls from biofouling caused by organisms drawn into the inner pipes of the cooling water system, and electrolytically generates chlorine compounds from seawater and injects ecotoxic chlorine compounds into the cooling water system. The residual chlorine concentration is estimated to be 0.15 to 0.3 mg/L (as Cl_2) when electrolyte is injected into the seawater electrolysis system through the inner piping of the cooling water system. The above concentrations are similar to the acute toxicity value for marine organisms (LC_{50}), however, the time from injection to discharge is generally only several seconds to tens of seconds long. Consequently, the seawater electrolysis system usually has only a moderate and transient effect, making it to prevent from attachment of organisms onto the inner piping but not actually killing the organisms drawn into the cooling system. Since there are no data or information available on the antifouling performance of the seawater electrolysis system, it would be desirable to evaluate the system in a standardized performance test similar to that used for self-polishing antifouling paint.

3.0.10 The price of seawater electrolysis systems used for the inner piping of cooling water systems varies in accordance with the different amounts of seawater treated. Japanese manufacturers provide products for common container vessels at a cost of several million yen and for LNG vessels and turbine ships for approximately 10 million yen. The effective lifetime of such products is approximately 15 years. The maintenance operation only involves replacement of the platinum anode in the electrolyzer at scheduled intervals and costs hundreds of thousands to millions of yen.

3.0.11 There is a possibility that the seawater electrolysis system could be improved and the application site extended from the inner piping of the cooling water system upstream to the sea chest where biofouling is severe. To achieve this it would be necessary to improve the injecting nozzle and inject highly concentrated electrolyte. Increasing the number of nozzles and evenly ejecting electrolyte over the entire wall would also improve effectiveness. Preferably, highly concentrated electrolyte should only be injected in harbor because organisms usually attach themselves to the cooling water system while a ship is at anchor. It would also be sensible to inject highly concentrated electrolyte at intervals while in harbor in order to reduce the number of attached organisms by preventing those organisms that have not been killed from slipping back into the system. On the other hand, it is also necessary to fully assess the corrosive effects of highly concentrated electrolytes on the sea chest and inner piping of the cooling water system. Furthermore, the risk posed by residual chlorine and byproducts in the discharge water to organisms in the surrounding environment should also be fully assessed and the electrolyte should only be used under acceptable conditions. Such improvements in the seawater electrolysis system are technically possible.

4. The current AFS device and technique for removing attached organisms, and its possible future improvement

4.0.1 An anti-fouling system (AFS) is defined as a device/treatment used to prevent or control biofouling of ship hulls. The definitive aims of AFS are [1] antifouling: to prevent or inhibit biofouling itself, and [2] biofouling removal: to restore the conditions without biofouling by scraping off biofouling organisms. In this chapter, AFS treatments used for [2] (hereinafter referred to as removal techniques) are evaluated in terms of their performance, risk, cost and the potential for future improvement. A removal technique is a surface-processing technique used to physically remove organisms attached to the outer hulls and sea chests of ships although antifouling treatment including antifouling paint and seawater electrolysis system have been applied. Since the aim is to restore the antifouling painted surface to the same or almost same condition as the original surface, this is an important AFS treatment as well as an antifouling treatment [1].

4.0.2 Removal techniques for biofouling organisms defined as AFCS include ship cleaning carried out in dock and in-water cleaning (IWC) of the outer hull skin. Ship cleaning in dock is usually carried out on all ships as part of the antifouling paint reprocessing involved in regular maintenance at 2.5-year intervals. On the other hand, IWC is conducted as a mean of antifouling paint maintenance between dock visits in order to minimize the increase in fuel consumption caused by biofouling organisms. Currently, IWC is the main technique used to remove potentially invasive organisms from ship hulls. Therefore, if IWC can be scientifically proven to reduce the amount of alien species dose being transferring, based on an international consensus, it can be considered an effective technique for inclusion in a comprehensive antifouling control system. In this research, IWC is considered to be primarily a technique for reducing the amount of alien species being transferring. In this chapter, the two kinds of removal technique, i.e., ship cleaning and in-water cleaning described above are evaluated in terms of the cleaning procedures employed, their removal performance, cost, the disposal method adopted for the materials removed, and outstanding issues to be resolved in the future.

4.0.3 Cleaning of the hull surface in dock is currently performed on almost all ships for biofouling removal. The procedures used involve cleaning the ship body (removal of attached organisms), base-coating, rust-proofing (touch-up) and antifouling painting. Each ship is cleaned until no further organisms, including the slime layer and seaweed predominantly attached to the sides and bottoms of hulls, along with barnacles, clams and sand worms on complex ship parts, can be detected in a gross inspection. Organisms removed by cleaning are collected along with other attached materials using a collecting device such as a bulldozer and disposed of on land. During this cleaning process, minimal amounts of antifouling paint containing active substances are removed from the ship surface and are possibly released into the surrounding sea area instead of being collected. However, the amount is not large enough to cause any bioinvasion or chemical environmental risk in the surrounding sea area. Although the current risk caused by ship cleaning in dock is not high enough to cause concern, it is still necessary to reduce the amount of releasing materials in cleaning included in the discharge water at dock as much as possible now and in the future. The current cost of ship cleaning, including the antifouling paint and base coat, is estimated to be 9 to 80 million yen, although this depends greatly on the size of the ship and the area of base coating and antifouling paint-reprocessing.

4.0.4 The increase in fuel consumption due to biofouling is caused by the increased friction and drag produced by the attached organisms on the outer hull while at sea and the associated decrease in actual propulsion power (engine power) even though the propeller itself is still revolving at the same speed. Therefore, IWC is conducted predominantly on outer hulls and propellers but rarely inside complex parts such as the sea chest which is not as directly related to the fuel consumption. IWC is currently conducted at 2-year intervals, on average. IWC is performed using a special device with brushes with different degrees of hardness corresponding to the types of organisms present. The cost of IWC depends on the size of the ship, the area to be treated and the degree of attachment, and the cost of IWC is estimated to be approximately 3 million yen/ship for an oil tanker (VLCC), collier (Panamax) or iron ore carrier (Cape Size).

4.0.5 In an example of IWC performed on a container ship coated with self-polishing antifouling paint to evaluate the current effectiveness of IWC, it was found that a ship with severe biofouling had to be treated with an extremely hard brush (high removal performance) to completely remove all attached materials. As a result, not only the attached organisms but also some of the antifouling painted surface, including the base coat, were damaged. IWC using an extremely hard brush such as a swaging brush is usually only performed on those parts of the ship that are heavily covered with organisms (approximately 10% of the entire area of the ship). On those areas where biofouling is not severe (approximately 90%), a soft nylon brush is used.

4.0.6 At present, the removed materials from IWC are not collected. Therefore, an important factor to consider in any potential improvement in environmental protection is the collection of attached organisms and preventing any detached organisms and antifouling paint chips being released into the water. Based on the current technique, it was estimated that almost 100% of the removed materials (0.3 mm or more in size) could be recovered using a collecting system with a net attached to the IWC device. This size is similar to that of barnacles, clams and sand worms in the early attachment phase. Consequently, almost all organisms can be collected without releasing them into the sea area where IWC is being performed. Therefore, if the improved IWC system proposed in this chapter is adopted as an appropriate treatment technique, it could be expected to substantially decrease the degree of environmental risk posed by transferring species and chemical compounds.

4.0.7 In IWC, a soft brush is preferable in consideration of the risk of removal of the antifouling paint The use of a soft brush minimizes antifouling paint depletion by reducing damage to the antifouling painted surface and prevents any reduction in antifouling efficacy. Use of a soft brush for IWC is expected to reduce antifouling paint damage, leading to a reduction in chemical environmental risks and prolonging the life span of antifouling paint.

4.0.8 The adoption of net collection for removed materials during IWC is an effective measure to reduce environmental risk. The collection of IWC-removed materials using a collection net not only reduces the release of organisms (part of the removed materials) into the sea but also decreases the release of active substances from the antifouling paint materials. Consequently, these collection measures can contribute to a decrease in both the risk of organisms being transferring and the degree of chemical environmental risk. Since the magnitude of the reduction effect depends on the mesh size of the collection net used, the minimum mesh size for an IWC net and the particle size of the removed paint chips by the net were measured and evaluated. Based on the results obtained, it was concluded that the net used for IWC needed to be able to collect materials with a particle size of 0.3 mm or more. Another means of reducing the amount of attached organisms would be to bring all removed materials, including organisms and surrounding seawater, to a treatment device on land using a pump. However, such a device would need to be very large.

4.0.9 The efficiency with which all removed materials are collected is also an important consideration when trying to reduce chemical environmental risks associated with the release of antifouling paint chips into the sea area during IWC. If IWC can be carried out under internationally agreed and controlled conditions, it could be an important treatment technique for comprehensive antifouling control systems in the future. To establish such a comprehensive antifouling system, based on scientific evidence, it is necessary to assess the chemical risks and the amounts of transferring organisms associated with IWC. Furthermore, the effectiveness of removal and collection should be confirmed in validation tests on ships that have actually been treated with IWC. The shorter the interval between IWC treatments, the shorter the biofouling period will be, i.e., the number of organisms attached to a ship will be reduced as the growth period is shorter and, consequently, the number of sexually mature organisms will also be reduced. Therefore, in chapter 6, changes in the numbers of organisms released into sea areas when IWC is conducted at 6-month or 1-year intervals are evaluated.

4.0.10 The adoption of a device to remove organisms from complex parts such as sea chests and propellers is evaluated as another possible area for further improvement. Since the sea chest grating is difficult to open and close in water and since the organisms attached to the sea chest do not increase the resistance of a ship at sea, only a limited amount of attached material is removed at present, and all removal is performed by hand. The development and adoption of new devices to improve removal performance and collect all removed materials would decrease both the amount of attached organisms present and the associated chemical environmental risks. Consequently, it was suggested that an improved conventional cleaning device equipped with collecting tools for removed materials should be applied to complex parts such as the sea chest and propellers.

4.0.11 Any future IWC system for removing organisms should have the following performance characteristics: [1] the maximum performance and the minimum operation time associated with power-assisted IWC in order to reduce the workload on divers; [2] the use of brushes that do as little damage to antifouling painted surface coatings as possible; [3] a system to prevent the release of detached organisms and coating paints/chips during IWC. [4] a system in which the organisms collected and the coating paints removed can be treated and disposed of on land, with the whole operation completed during the time taken for normal cargo loading/unloading, i.e., without interfering with the ship’s schedule.

4.0.12 The main issues to be addressed before adopting the IWC technique as part of a comprehensive antifouling system are to expand the use of the IWC system and to ensure the availability of IWC companies. In order for IWC to come into common use around the world, it will be necessary to develop and adopt an IWC system with acceptable collection performance, and ensure that facilities and equipment are in place that can conduct IWC effectively. In Japan, it has been confirmed that there are two IWC companies already have a system for collecting removed materials in place, as of 2010.

5. Chemical environmental risks

5.0.1 The various approaches used for reducing biofouling can be classified into two major groups: antifouling techniques (used to prevent or inhibit biofouling), and removal techniques (scraping off the fouling organisms). An antifouling coating system (AFCS) is applied to the hull outer skin (antifouling paint is a typical AFCS). A marine growth prevention system (MGPS) is commonly applied to more complex ship components (with the exception of the hull outer skin) and the seawater electrolysis system is a leading MGPS. The most widely used and highly effective antifouling treatment for the hull outer skin is self-polishing antifouling paint containing specific compounds to prevent biofouling. The effectiveness of antifouling paints is associated with the active substances containing in these paints. Consequently, there is always some concern regarding possible chemical environmental risks associated with the use of AFCS, e.g. residual toxicity to aquatic ecosystems. Therefore, quantitative environmental risk assessment has already been conducted by various industry associations. On the other hand, a different treatment (IWC: in-water cleaning) is used to remove biofouling from the hull outer skin and complex components. Australia and the United States have pointed out some concerns that treatments used for biofouling removal, e.g. excessive scraping off of paint by IWC, can actually increase the environmental burden produced by the compounds released, in addition to the normal leaching of compounds from antifouling paints.

5.0.2 In this chapter, chemical environmental risks are assessed for: [1] the leaching of compounds from antifouling paints used to prevent biofouling, [2] the use of the seawater electrolysis system, a leading MGPS which uses chlorine compounds as its active substances, and [3] IWC implementation to remove biofouling. Each exposure scenario used to assess the environmental risk was established for both the current basic treatment and for the improved treatment that is expected to improve antifouling performance in the future and form the basis of a comprehensive control system.

5.0.3 In this study, environmental risk assessment was conducted by comparing the Predicted Environmental Concentration (PEC), which is widely used domestically and internationally, and the Predicted No Effect Concentration (PNEC), estimated using toxicity data and assessment factors, i.e., PEC/PNEC. Exposure scenarios for the 3 techniques described above were established and the assessment process was carried out using the PEC/PNEC of compounds estimated using the Marine Antifoulant Model (MAM)-PEC model (a numerical model designed to simulate the environmental behavior of compounds), which is frequently used by IMO.

5.0.4 During the environmental risk assessment process for the use of antifouling paint, the active substances found in the most popular self-polishing antifouling paints, pyrithione zinc, pyrithione copper, total copper and total zinc, were each assessed individually. In the exposure scenario, the total area of hull surface in a model port was estimated from statistical data and the emission rate (g/day) was estimated by multiplying this value by the leaching rate of each compound, as stated in references. The PEC was estimated from the emission rate using the MAM-PEC model designed to estimate concentrations in the environment. Consequently, the PEC/PNEC for the use of antifouling paints, the current basic treatment, was estimated in a scenario in which compounds leach from the entire ship hull. The estimated PEC/PNEC of pyrithione zinc was the largest, followed by pyrithione copper, total copper and total zinc. Since the PEC/PNEC of all compounds was around 1, the threshold value, it was considered that further environmental risk assessments were required.

5.0.5 In the scenario used for compounds leaching from complex ship parts (except the hull outer skin), the result of hull outer skin (98% of the entire area of the exposed portion of the ship) was almost the same as the result for the whole vessel. On the other hand, the PEC/PNEC of all parts of the ship except the outer hull skin was less than 1 in all conditions. Therefore, the environmental risk of compounds leaching from any part of the ship other than the outer hull skin was considered to be extremely low.

5.0.6 In this assessment, it might be hasty to conclude that those compounds with PEC/PNEC≥1 in self-polishing antifouling paints in the exposure scenario used may pose unacceptable environmental risks at present. Since some of the parameter used for setting the conditions for the development of exposure scenario and the estimation of PEC and PNEC were insufficient and the worst cases were used, the risks could have been overestimated. Therefore, in order to conduct a much precise assessment, it would be advisable to collect additional data and assess full environmental risks in more detail. In order to estimate the environmental concentrations of compounds in sediment, it may also be necessary to improve current models and adopt a multi-media model. A full risk assessment of copper-related compounds is currently being carried out by the European manufacturers association and since the results are scheduled to be published up to the end of 2011, these results should be utilised to further assessment.

5.0.7 IWC, a technique designed to remove biofouling, is conducted on some vessels to ensure good fuel efficiency. In this survey, an exposure scenario was established based on the assumption that all ocean-going vessels were treated by IWC twice a year in a limited number of ports and that a significant degree of macro biofouling was encountered during IWC implementation. Furthermore, it was also assumed that, during current IWC implementation, most active substances had already leached out from the coated surface and the rate of leaching for the remaining active substances was lower than when the paint was originally applied to the hull. The PEC for IWC implementation was estimated based on the assumption that all compounds in removed paint chips by IWC were released into the surrounding sea area. Compounds assessed as a result of IWC implementation were the same as those used in the original antifouling paints. During the risk assessment carried out for IWC implementation, using Yokohama and Rotterdam as model ports, the current scenario produced a PEC/PNEC for pyrithione zinc and pyrithione copper greater than 1 but the PEC/PNEC of all other compounds was less than 1. However, in the exposure scenario used in this assessment, actual measurement data were not available. Therefore, it should be noted that the thickness of removed paint chips by IWC and the remaining active substances were estimated on the basis of certain assumptions.

5.0.8 Future IWC systems are to be implemented to prevent the transfer of biofouling organisms. Therefore, it is expected that the severity of macro biofouling encountered during IWC implementation will be less and that the active substances in paint chips scraped off by IWC will rarely leach out. Since this IWC system will be more widely used than it is at present, IWC is expected to become feasible in more ports. In the comparison of PEC carried out for compounds involved in IWC implementation in the current and future IWC scenarios, the environmental risk of future IWC was estimated to be appropriately 1/3.8 that of the current IWC system. Furthermore, if the paint chips scraped off are then recovered with a net, the increase in environmental risk is expected to be even smaller again for IWC.

5.0.9 The additional effect of IWC on environmental risk was estimated in comparison with the use of self-polishing antifouling paints (the current base treatment), alone. Consequently, the increase in environmental risk caused by IWC (in addition to that from antifouling paint) was largest, at approximately 35%, for total zinc and 1% for total copper in the current IWC scenario. Based on the above results, it was confirmed that IWC would not excessively increase chemical risks to environmental organisms. In future IWC implementation, the additional effect is estimated to be less than that of the current IWC.

5.0.10 In the assessment carried out for the seawater electrolysis system (a leading antifouling treatment applied to complex components in a similar manner to antifouling paint) a scenario was established, based on actual operation conditions, in which seawater electrolyte at a concentration of 0.3 mg/L of residual chlorine was injected into the cooling water.. A scenario for an improved antifouling technique that is expected to be introduced in the future was also established, based on the assumption that seawater electrolyte (1 and 3 mg/L of residual chlorine) was injected into the sea chest, etc. and the release volume was equal to that of the current technique. Since the PEC/PNEC was less than 1 in all of the current and improved scenarios, the chemical environmental risk of the seawater electrolyte itself was not considered to be of concern.

5.0.11 A total of 7 byproducts generated by the use of the seawater electrolysis system were assessed, including trihalomethanes and combined chlorine which are also generated in the ballast water management system - a similar treatment technique. The PEC/PNEC of chloramine (monochloramine), combined chlorine, exceeded 1. However, the PEC/PNEC of all other byproducts was less than 1. Since information on the generation/degradation mechanism, generation concentration, environmental fate, and the sensitivity of different species to chloramine was lacking, more data on chloramine generated from the use of seawater electrolysis system and its toxicity and environmental fate are needed.

5.0.12 To appropriately control the environmental risks posed by the compounds and techniques used to prevent/remove biofouling on ship hulls, it is important to quantitatively assess the risks on the basis of reliable chemical data and reflect the actual operations. Full environmental risk assessment requires additional data to optimize the exposure scenario, including reductions in the emission rate achieved by using a recovery net in IWC, the content of chemical compounds in paint chips scraped off by IWC, and an accurate determination of the leaching rates. The environmental risk assessment based on PEC/PNEC used in this assessment always requires the estimation (determination) of compound concentrations, however, compounds leaching from antifouling paints are expected to exist in extremely complex forms in actual environments. It may be difficult to accurately assess (determine) the existing forms and concentrations of individual compounds in actual environments using current analysis techniques and simulation models. It should also be noted that environmental organisms are exposed to various compounds in mixed conditions and that two or more compounds are often used simultaneously in antifouling techniques. Therefore, to accurately assess the environmental risks of compounds used in antifouling and removal techniques, their combined toxicity should be assessed. For example, environmental risk assessment by means of the whole effluent toxicity (WET) test, which does not require estimation (determination) of each individual compound concentration, is suitable for the risk assessment of antifouling techniques.

5.1 Assessment methods for chemical environmental risks

5.1.1 Summary of risk assessment methods

The relationship between the dose-response curve obtained from ecotoxicity studies and the indicators of test results, the No Observed Effect Concentration (NOEC), the Lowest Observed Effect Concentration (LOEC) and the 50% Effect Concentration (EC_{50}) is shown in Figure 5.1-1. The Predicted No Effect Concentration (PNEC) for the above indicators (by assessment factor) is widely used in the risk assessment process for compounds that may affect environmental organisms. The results of risk assessment using the PNEC and the Predicted Environmental Concentration (PEC) are shown in Figure 5.1-2. While the PNEC value is specific to compounds, the PEC depends on the exposure scenario. Environmental risk assessment using a ratio of PEC to PNEC (PEC/PNEC) is carried out by many international institutions including the EU and OECD. In general, a case of PEC/PNEC>1 indicates a long-term or acute/local risk.

In this study, chemical environmental risks were assessed using PEC and PNEC values that were estimated using the following procedure:

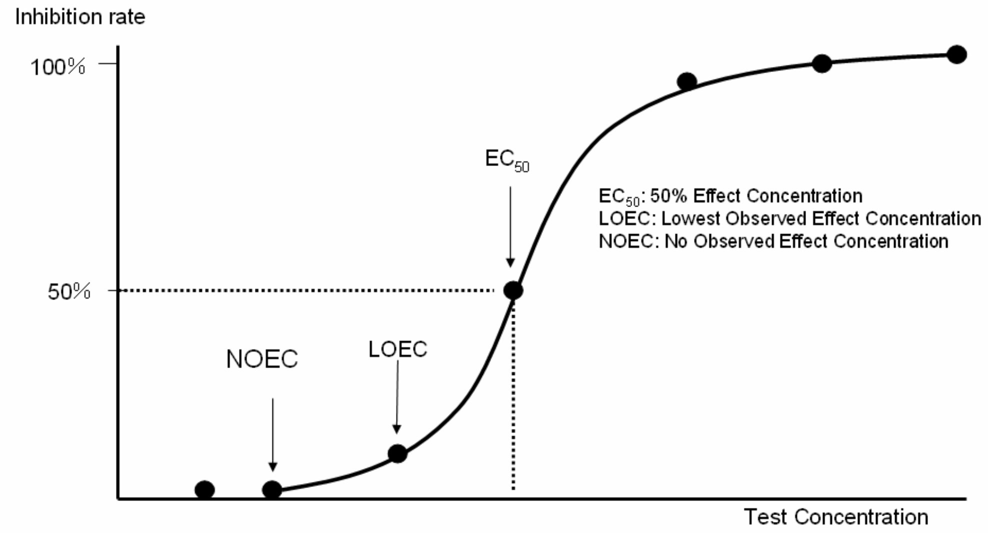


Figure 5.1-1 Dose-response curve of eco-toxicity data

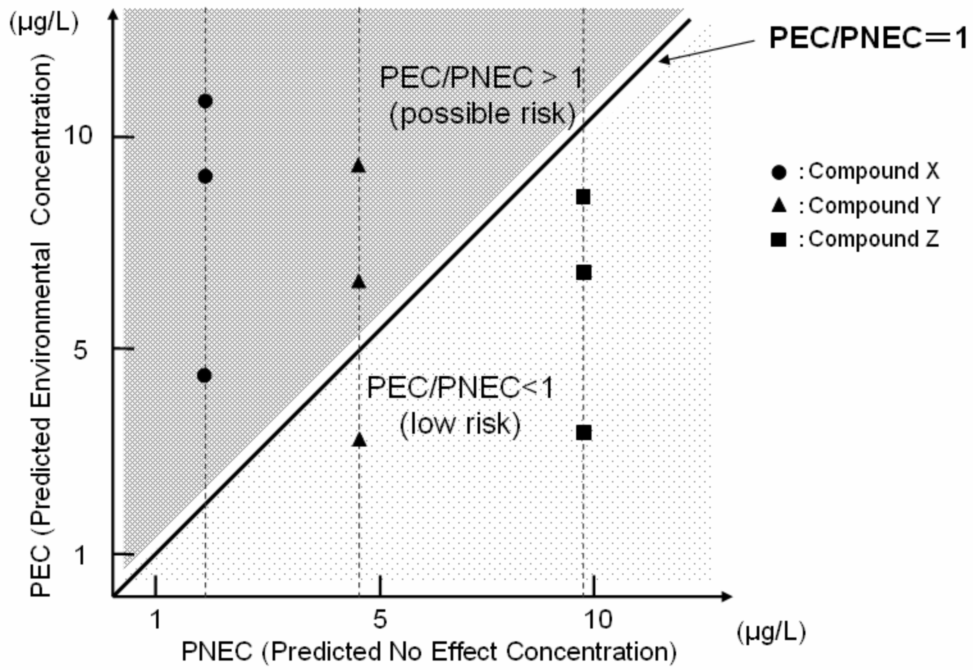


Figure 5.1-2 Distribution of PEC/PNEC ratios and assessment results

Each compound has single PNEC derived from hazard data (L/EC50) and assessment factor, however, PECs are variable and are depend on exposure scenarios.
Compound X may cause environmental risks because PEC/PNECs exceed 1 in all exposure scenarios. Compound Y is assessed that risk may or may not be concerned depending on exposure scenarios. Compound Z can be considered that there is low risk and no further assessment is required.

5.1.2 PEC estimation for risk assessment

To assess the chemical risks posed to environmental organisms by the techniques used to prevent/remove biofouling on ship hulls, the PEC in this study was estimated using the MAM-PEC model ver. 2.5, a simulation model.

When estimating PEC using the MAM-PEC model, the following parameters are required:

- Environmental conditions of a model port (geographical and meteorological conditions, etc.)
- Physicochemical properties and environmental fate data such as the degradability of compounds
- Release amounts for those compounds used in the technique for preventing/removing marine biofouling

The environmental conditions of a model port were established on the basis of map information and statistical data for Yokohama and Rotterdam Port. Physicochemical properties and environmental fate data were obtained from references and some of the data used were estimates of the Quantitative Structure-Activity Relationships (QSARs) involved. Exposure scenarios were based on the leaching rates of compounds used in antifouling paints obtained from references, statistical data for arrivals in the model port, data on hull surface areas provided by domestic shipbuilders, and information concerning operating conditions. The release amounts in each scenario were estimated.

The maximum and mean PEC in the model port and the surrounding water area used for risk assessment were estimated based on the following exposure scenarios, environmental conditions and parameters in a simulation model.

(1) Exposure scenarios

Exposure scenarios are the conditions that are established in order to estimate the environmental concentrations of compounds released into the environment. Exposure scenarios include the conditions of compound release sources, route and amounts, and the behavior of compounds in the environment (air, water and sediment). Since compound concentrations in the environment depend largely on the ranges of release amounts and areas, and the physicochemical environmental conditions of the release areas, it is important to establish these exposure scenarios (conditions for the estimation of environmental concentrations).

In this survey, care was taken not to underestimate the effect on organisms of compounds released into the environment during the use of antifouling paint, a leading AFCS treatment applied to the hull outer skin. To be specific, exposure scenarios were established based on the worst case, i.e., PEC was estimated based on the assumption that all ships arriving at a model port were treated with a single antifouling paint containing all the compounds to be assessed at the same concentration.

(2) Model ports

In this survey, the predicted environmental concentrations (PECs) of all compounds that leached out from the antifouling paint applied to the hull surface in the model ports of Yokohama and Rotterdam were estimated. Yokohama Port was selected because it has the largest number of foreign vessels arriving of any Japanese port (the Ministry of Land, Infrastructure, Transport and Tourism, hereinafter referred to as MLIT, 2006) and because ocean-going vessels on the North American, Middle Eastern and Australian routes, which are subject to comprehensive control of biofouling, arrive in Yokohama Port most frequently. Rotterdam Port handles the third largest volume of freight in the world and is the largest port in Europe. Rotterdam Port is located on the Rhine estuary and is relatively deep in comparison with its width, i.e., it was selected as a typical port which is, however, different from Yokohama in terms of the water environment and seawater exchange, both of which are considered to have some effect on the environmental behavior of leaching compounds.

(3) Simulation model used for PEC estimation and parameter setting

Many simulation models, mathematical models, diffusive equilibrium and multimedia models have been developed and applied to the prediction of environmental behavior and the concentrations of compounds released into the water environment (van Hattum et al. 2006). In this survey, the latest version of MAM-PEC model ver. 2.5 (released in October 2008) which was developed by the European Council of the Paint, Printing Ink and Artists' Colours Industry (CEPE) was applied to the PEC estimation of compounds leaching from antifouling paints into the sea area of a port. This model has already been used by industry associations as an effective model for the assessment of compounds used in the AFCS process and is referred to by the guidelines for assessment which are scheduled to be submitted to the International Organization for Standardization in 2011. The International Maritime Organization (IMO) also recommends this model for the estimation of compounds in ballast water released in port areas.

When estimating PEC using the MAM-PEC model, the following 3 parameters are required:

- Environmental parameters in the model port
- Physicochemical properties and environmental fate data such as the degradability and bioaccumulation of the compounds being assessed
- Amount of each compound released (g/day), estimated by different exposure scenarios

a) Environmental parameters in a model port

The data on geography, physical environments and water quality, which characterize marine environments, were obtained from published government information, reports and scientific articles and were arranged into input-formats for the MAM-PEC model.

The environmental parameters of model ports required for PEC estimation by the MAM-PEC model are shown in Table 5.1-1 (Reference-2).

Table 5.1-1 Environmental conditions in Yokohama and Rotterdam ports applied for PEC calculation

	Yokohama	Rotterdam
Tidal period (hours)	12.41	12.41
Silt concentration (mg/L)	1.3	35
POC concentration (mg-OC/L)	1.1	1
DOC concentration (mg/L)	2.3	2
Chlorophyll (μg/L)	3	3
Salinity	28	30
Temperature (°C)	18.3	15
Latitude (degree NH)	35	50
pH	8.4	8
Depth mixed sediment layer (m)	0.1	0.2
Sediment density (m)	1,000	1,000
Fraction organic carbon in sediment	0.054	0.03
Nett sedimentation velocity (m/d)	0.5	1
Layout: x1 (m) (Length of river, not part of harbour)	1,000	2,000
x2 (m) (Length of harbour)	2,200	2,000
y1 (m) (Width of harbour)	5,400	20,000
y2 (m) (Width of river)	1,000	2,000
Depth (m)	11.2	20
Mouth Width x3 (m)	1,000	2,000
Flow velocity (m^3/s)	1.5	1.5
Calculated exchange volume (m^3/tide)	1.90×10^7	1.09×10^8
Tidal difference (m)	1.5	1.5
Max. density difference tide (kg/m^3)	0	0.8
Non tidal daily water level change (m)	0	0
Fraction of time wind perpendicular (-/-)	0	0
Average wind speed (m/s)	1	1
Flush (m^3/s)	0	0
Max. density difference flush (kg/m^3)	0	0
Depth at harbour mouth (m)	11.2	20
Exchange surface area at harbour mouth (m^2)	11,200	40,000

b) Physicochemical properties and environmental fate data for compounds leaching from hull surfaces to which antifouling paint has been applied

The physicochemical properties and environmental fate data of compounds whose PEC was estimated by the

MAM-PEC model are shown in Table 5.1-2. The physicochemical properties of total copper and zinc refer to the dissolved form (water-soluble compounds), therefore, PEC was estimated using the MAM-PEC model under the following conditions: vapour pressure = 0 and water solubility = 100 g/cm^3. Since copper I oxide, total copper and total zinc are inorganic metal compounds, during PEC estimation using the MAM-PEC model no consideration was given to parent compound disappearance due to degradation and configuration change or to distribution between different environmental compartments (by partition coefficient), regardless of the actual behavior of these compounds in the environment.

Table 5.1-2 Phisico-chemical properties and environmental fate of active substances

Chemical name	CuO	Zinc pyrithione	Copper pyrithione	Total copper (dissolved)	Total zinc (dissolved)	TBT
CAS number	1317-39-1	13463-41-7	14915-37-8	—	—	—
Molecular weight	143.10	317.71	127.17	63.5	65.38	290.04
Vapour pressure (20 °C, Pa)	1.0×10^{-10}	1.0×10^{-6}	1.79×10^{-4}	0.0*	0.0*	8.5×10^{-5}
Wat. Sol. (20 °C, g/m^3)	0.6	6.0	8.0	100*	100*	19
Deg. rate (20 °C) Abiotic : in water Abiotic : sediment Photolysis: in water Photolysis: sediment Biodeg.: in water Biodeg. : sediment	—	 5.6×10^{-3} 0.0 5.8×10^{-3} 0.0 2.1 7.9	 5.4×10^{-2} 0.0 34.0 0.0 0.17 0.0	—	—	 0.046 0.0 0.033 0.0 1.9×10^{-3} 1.9×10^{-3}
Kd (only metals)	30.0	—	—	30.0	30.0	—
LogPow	—	0.9	0.9	—	—	3.8
LogKoc	—	3	0.7	—	—	4.6
Henry lawconctant (Pa-m^3/mol)	—	5.0×10^{-5}	2.49×10^{-3}	—	—	0.02
Metal compound	○	—	—	○	○	—
Organic compound	—	○	○	—	—	○
Copper compoun	○	—	—	○	—	—

Vapour pressure = 0 and water solubility = 100 g/m^3 are used for copper and zinc because both compounds are assessed as a dissolved form.

5.1.3 Estimation of PNEC for risk assessment

(1) Survey of ecotoxicity study data and assessment methods

Risk assessment of ecotoxicity is generally conducted using the lowest observed adverse effect level (LOAEL) in ecotoxicity studies involving the three types of test organism (algae, crustaceans and fish) adopted by international institutions in consideration of data reliability. Ecotoxicity studies are classified as either acute or chronic toxicity studies based on the studies period (time) and the life stage of the test organisms involved. In this study, the 50% lethal concentrations (LC_{50}) and 50% Effect Concentrations (EC_{50}) obtained from toxicity studies (generally for 96 hours or less) were adopted as acute toxicity data. The No Observed Effect Concentration (NOEC) with endpoints of growth, reproduction (egg production and hatching rate, etc.) and embryonic and larval development (including teratogenesis) obtained from toxicity studies (generally for 14 days or more) were adopted as chronic toxicity data. The information sources for the data used in this study included the risk assessments carried out by many foreign governmental and international institutions (EU Risk Assessment Report, etc.), databases (ECOTOX database, etc.) and scientific articles. After the reliability of ecotoxicity study data collected was assessed, taking into consideration all domestically and internationally approved compliance guidelines and the methods based on them, along with the study conditions and organisms involved, and the physicochemical properties of the test compounds, these data were then used for PNEC estimation. In general, the NOEC of each compound was based on the data from toxicity studies with endpoints of mortality, growth and production. If chronic data on the relevant compounds were not available, the LC_{50}/EC_{50} obtained from acute toxicity study data was adopted and the PNEC was estimated from the LC_{50}/EC_{50} using a constant assessment factor.

(2) Establishment of assessment factors for PNEC estimation

General environmental risk assessments estimate the PNEC using assessment factors based on a combined set of all available data. In this study, the PNEC was estimated from ecotoxicity study data obtained in accordance with the guidance documents of international institutions such as the EU Technical Guidance Document, using the assessment factors shown in the following table.

Table 5.1-3 Recommended assessment factor

Category	Assessment factor
Acute toxicity data that can be trusted available	1,000～10,000
Data on reliable chronic data of one or two species available	50～100
Data on reliable chronic data of three species (algae, invertebrate, fish) available	10

The assessment factors in the above table are based on chronic toxicity study data for three types of organism (algae, crustaceans and fish) which are typically found in trophic levels 1 - 3. In those cases where PNEC estimation fulfills at least two of the following criteria shown in Table 5.1-4, a product of the assessment factors is used for PNEC estimation.

Table 5.1-4 Criteria to derive assessment factor

Criteria	factor
Application of laboratiry study to the environment	10
Chronic data, i.e. NOEC on three trophic level available	1
Chronic data, i.e. NOEC on two trophic level available	5
Chronic data, i.e. NOEC on single trophic level available	10
Estimating chronic toxicity from acute data	100

An adjustment factor may be added in the following cases:

- Acute toxicity study data are available for some species.
- LOAEL is estimated on the basis of species sensitivity.
- Data are available for a seawater environment.
- Useful population data are available for organisms other than the 3 types listed above.

(3) Estimation of PNEC

The most reliable and lowest LOAEL reported in available ecotoxicity study data (NOEC or LC/EC$_{50}$, etc.) was adopted and the PNEC was estimated using assessment factors based on a combined set of all available data.

5.1.4 Assessment of chemical risks to environmental organisms

Chemical risks to environmental organisms were assessed by comparing a PEC estimated by the MAM-PEC model in the exposure scenarios adopted in this study and a PNEC estimated from ecotoxicity study data published in references and assessment factors.

In those cases where the result of risk assessment was PEC/PNEC > 1, the environmental risk of the test compound was not considered to be of concern. Even if the result was PEC/PNEC ≥ 1, the environmental risk was not considered to be of immediate concern. However, further discussion was required to consider the degree and cause of uncertainty in the calculation/input conditions and additional information was necessary for a full risk assessment because the PEC estimate was based on exposure scenarios derived from limited information. In these cases, the PEC was considered as a screening result in an initial risk assessment.

5.2 Risk assessment of common techniques currently in use

The most common treatment used to prevent or reduce biofouling on ships is the application of AFCS to the hull outer skin and antifouling paint is a leading AFCS. Another common antifouling treatment used for seawater cooling systems (piping) and sea chests is the marine growth preventive system (MGPS) and the seawater electrolysis system, which uses chlorine compounds as active substances, is a leading MGPS. The chemical risks posed by these techniques to environmental organisms in the surrounding water area were assessed by developing specific exposure scenarios for each technique.

5.2.1 Risk assessment of compounds leaching from antifouling paint applied to the hull surface and their effect on environmental organisms

(1) Compounds to be assessed

In this study, 5 compounds that are widely used as active substances in antifouling paints were selected and assessed in terms of their chemical environmental risk, as follows:

- Copper (I) oxide
- Zinc pyrithione
- Copper pyrithione
- Total copper (copper as dissolved total copper)
- Total zinc (zinc as dissolved total zinc)

Tributyltin (TBT) was selected as a control and its environmental risks were similarly assessed. Since the form of copper (I) oxide found in aquatic environments after leaching from antifouling paint is unknown, it was assessed as reference data.

(2) Estimation of PNEC

The LOAELs reported in ecotoxicity studies, and the assessment factors and PNECs of the test compounds copper (I) oxide, pyrithione zinc, pyrithione copper, total copper (copper as dissolved total copper) and total zinc (zinc as dissolved total zinc) and a TBT control are shown in Table 5.2-1 (see Reference-3).

The full risk assessment of pyrithione copper published by the National Institute of Advanced Industrial Science and Technology (AIST) used a PNEC of 2.5 ng/L, similar to that used in this assessment.

Table 5.2-1 NOECs, assessment factors and PNECs

Chemical name	NOEC (ng/L)	Assessment factor	PNEC (ng/L)
Copper (I) oxide: Cu_2O*	20,000	1000	20
Zinc pyrithione	1,100	100	11
Copper pyrithione	250	100	2.5
Total copper (dissolved form)	5,200	2	2,600
Total zinc (dissolved form)	26,000	50	520
TBT	2.7	10	0.27

*PNEC for CuO is a reference data and not used for risk assessment

Literature:

NITE-CERI (2005) Initial Risk Assessment Report. Zinc compound (water-soluble)

OPRF (2008) comprehensive study to prevent macro-fouling on the surface of AFCS

(3) Establishment of exposure scenarios

Published government statistical data and information obtained from the results of reference surveys were collated and the following exposure scenarios were established to assess the risks to environmental organisms. The release of compounds was estimated by different exposure scenarios and the PEC was estimated using the MAM-PEC model.

a) The number of vessels arriving in ports and time spent in port

The number of vessels arriving in Yokohama Port was obtained from 2006 data on arrivals published by the Port and Harbour Bureau of Yokohama City (excluding fishing and harbour vessels). However, since this included vessels that arrived in port facilities outside the area used for PEC estimation in this study, the data were corrected based on the percentage of vessels moored in Yokohama Port, by year (2000 data). The time spent in port by each arriving vessel was estimated by summing total anchoring time and time spent at a pier, obtained from data for Yokohama Port in 2000 and dividing the total by the number of vessels (ocean-going vessel: 20 hours, coastal vessel: 9.3 hours). The transit time in port was 1 hour for both ocean-going and coastal vessels.

In the estimation for Rotterdam Port, data for the number of arriving vessels, time spent in port and transit time (port time: 20 hours, transit time: 3 hours) were obtained from reference material (Salmons 2001).

b) Estimation of the area of underwater hull surface and the amounts of compounds leaching out from ships with antifouling paint applied

In the estimation for Yokohama Port, the area of underwater hull surface was estimated separately by vessel type (classified into pure car carrier, tanker/tank barge, passenger/cargo/Ro-Ro vessel, container/bulk carrier, and other vessel)—each with different lengths and gross tonnages. In the estimation for ocean-going vessels, the ship length was estimated from the data for the mean gross tonnage (by vessel class) of arrivals in Yokohama Port. This was achieved by using an equation derived from the Lloyds vessel specifications data, and the hull bottom area of each vessel (by vessel class) was then estimated using the Froude equation. Likewise, in the estimation for coastal vessels, the mean gross tonnage was first estimated (by class) from the Japan vessel specifications data and then mathematically converted to the length of ship. Then, the hull bottom area of each vessel with a given mean gross tonnage was calculated from the estimated length using the relevant equation in the MAM-PEC model. In the estimation for Rotterdam Port, the data obtained from the abovementioned reference were used without change.

The total amounts of compounds leaching from vessels in each port per day (E_{AFCS}: g/day) were calculated using the following equation as an input value for the MAM-PEC model:

$$E_{AFCS} = \sum (A \times N \times T) \times L$$

Where,
A = total area of underwater hull surface,
N = number of vessels arriving at the model port,
T = port time, and
L = leaching rate of compounds.

c) Leaching rate and amounts of compounds released

It is difficult to accurately measure the leaching rate of compounds from a surface painted with antifouling paints. It has also been pointed out that the leaching rate estimated by conventional methods is often overestimated in comparison with the leaching rate actually found in marine environments. Therefore, the Working Group (TC 35/SC 9/WG 27) of the International Organization for Standardization (ISO) is comparing different methods to assess the leaching rates from antifouling paints, including mass-balance calculation (ISO/DIS 10890) and a direct determination carried out on the coating layer of painted ships in addition to the existing standard laboratory determination (ISO 15181). From an antifouling perspective, the dissolution amount (rate) of paint compounds entering the seawater is especially important and physical abrasion and flaking are not considered. On the other hand, in terms of these compounds' effects on marine environments, leaching from painted pieces (particles) physically separating from the painted surface by flaking and abrasion are considered to contribute to the burden on the environment. Therefore, in a worst-case scenario for the environmental risk assessment of compounds leaching from antifouling paints-applied vessels, it is reasonable to estimate the PEC based on the total amounts of compounds leaching from painted pieces scraped off the painted surface. In this assessment, if two or more sets of existing data on leaching rate were available, the highest values were adopted as the inputs for the MAM-PEC model. If no existing data on the leaching rate were available and the content data of compounds in painting products had to be obtained from references, the highest leaching rate that was estimated (considering the content ratio to other antifouling compounds used in the relevant product) was adopted as the input for the model. The leaching rate of compounds for which no content data in products were available was set at 5 $\mu g/cm^2/day$, corresponding to the upper limit of the above mentioned estimates.

In the MAM-PEC model, the leaching rates in harbour and at sea are established separately. However the leaching rate in harbour was assumed to be equal to that at sea in this assessment. Table 5.2-2 shows the amounts of compounds leaching out, estimated from the leaching rate and the area of underwater hull surfaces in the model port. Since the leaching rates of total copper (dissolved) and total zinc (dissolved) were not available, the leaching rates of copper (I) oxide and pyrithione zinc were corrected on the basis of molecular weight and applied to the estimation.

Table 5.2-2 Leaching rate and emission volume of active substance

CAS number	Chemical name	Leaching rate ($\mu g/cm^2/day$)	Emission volume (g/day)	
			Yokohama	Rotterdam
1317-39-1	Copper (I) oxide: Cu_2O*	40	51,984	398,976
13463-41-7	Zinc pyrithione	4.57	5,939	45,583
14915-37-8	Copper pyrithione	2.88	3,743	28,726
—*	Total copper (dissolved form)	—	46,135	354,091
—*	Total zinc (dissolved form)	—	1,222	9,380
—*	TBT	1.9	2,469	18,951

*：No CAS number identified

(4) Estimation of PEC

The highest and mean PECs in Yokohama/Rotterdam Port (harbour and surrounding sea area) that were estimated by the MAM-PEC model, using the leaching amounts from the abovementioned exposure scenario and other parameters, are shown in Table 5.2-3 and Table 5.2-4. In the assessment of total copper (dissolved), the background concentration of copper and copper compounds reported in the EU Risk Assessment, 0.36 μg-Cu/L, was used as the background concentration in calculations involving the MAM-PEC model.

The PEC of copper (I) oxide and total copper (dissolved) estimated from the highest concentration in the harbour ranged from 911 to 2,490 ng/L and the PEC of pyrithione zinc and total zinc (dissolved) ranged from 20 to 56 ng/L. The PEC of pyrithione copper was around 5–7 ng/L.

In the PEC estimation of inorganic compounds, the leaching rate had a significant effect on the PEC and, consequently, the PEC of copper (I) oxide and total copper (40 $\mu g/cm^2/day$) with the largest leaching rate was higher than the PEC of other compounds. The effects of pyrithione copper and pyrithione zinc depend largely on the degradation rate, and the PEC of pyrithione copper (with the most rapid degradation rate) was the lowest of all the compounds assessed.

Table 5.2-3 PEC of active substance in Yokohama port

Chemical name	In harbour PEC (ng/L)		Surrounding PEC (ng/L)	
	Max.	Average	Max.	Average
Copper (I) oxide: Cu_2O*	2,390	1,480	62.6	19.5
Zinc pyrithione	54.5	21.9	0.53	0.17
Copper pyrithione	5.37	0.82	6.07E-05	1.62E-05
Total copper (dissolved form)	2,490	1,680	416	378
Total zinc (dissolved form)	56.3	34.9	1.47	0.46
TBT	89.9	54.6	2.26	0.71

*PNC for CuO is a reference data and not used for risk assessment

Table 5.2-4 PEC of active substance in Rotterdam port

Chemical name	In harbour PEC (ng/L)		Surrounding PEC (ng/L)	
	Max.	Average	Max.	Average
Copper (I) oxide: Cu_2O*	911	505	35.5	18.4
Zinc pyrithione	78.9	31.7	1.35	0.70
Copper pyrithione	6.94	1.05	9.63E-05	4.41E-05
Total copper (dissolved form)	1,169	808	392	376
Total zinc (dissolved form)	21.4	11.9	0.84	0.43
TBT	79.7	43.6	3.03	1.57

*PNC for CuO is a reference data and not used for risk assessment

(5) Results of risk assessment (PEC/PNEC)

The PEC/PNEC was calculated using the PEC of compounds estimated in the above paragraph (4) and the PNEC estimated in paragraph (2), (Table 5.2-5, Table 5.2-6).

In those cases where the PEC was the largest in a port, the PEC/PNEC of pyrithione zinc and pyrithione copper exceeded 1. In the calculations carried out for total copper (dissolved) and total zinc (dissolved), the PEC/PNEC was less than 1 in all conditions.

Table 5.2-5 PEC/PNEC of active substance in Yokohama port

Chemical name	In harbour PEC/PNEC		Surrounding PEC/PNEC	
	Max.	Average	Max.	Average
Zinc pyrithione	5.0	2.0	0.048	0.015
Copper pyrithione	2.1	0.33	< 0.01	< 0.01
Total copper (dissolved form)	0.96	0.65	0.16	0.15
Total zinc (dissolved form)	0.11	0.07	< 0.01	< 0.01
TBT	333	202	8.4	2.6

Table 5.2-6 PEC/PNEC of active substance in Rotterdam port

Chemical name	In harbour PEC/PNEC		Surrounding PEC/PNEC	
	Max.	Average	Max.	Average
Zinc pyrithione	7.2	2.9	0.12	0.06
Copper pyrithione	2.8	0.42	< 0.01	< 0.01
Total copper (dissolved form)	0.45	0.31	0.15	0.14
Total zinc (dissolved form)	0.041	0.023	< 0.01	< 0.01
TBT	295	161	11.2	5.8

It might be premature to immediately conclude that all compounds with PEC/PNEC≥1 in the active substances of self-polishing antifouling paints leaching out from a hull surface to which antifouling paint has been applied pose unacceptable levels of environmental risk at present. This is because risks can be overestimated as the amount of information available for some of the parameters used for estimation of the PEC and PNEC in this assessment was insufficient and the worst cases were applied to the estimation process. To be specific, the PEC used in this assessment could be much higher than concentrations found in actual marine environments because changes in the chemical form of compounds leaching into the water from the hull surface were not considered. Especially in seawater containing many natural chelates and buffers, the chemical form of the compounds considered in this assessment (antifouling compounds containing metals) probably undergo changes. In addition, when estimating on the basis of limited ecotoxicity data sets, large assessment factors were applied. For example, in estimating the PEC based only on the study data available for copper (I) oxide reference data, the LOAELs of copper (I) oxide and total copper (dissolved) were 20,000 and 5,200 ng/L, respectively. However, the PNECs were only 20 and 2,600 ng/L because the assessment factors of copper (I) oxide and total copper (dissolved) were 1,000 and 2, respectively.

Consequently, in a full environmental risk assessment, additional data should be collected to review the above PECs and PNECs and environmental risks should be assessed again on the basis of the revised values. A full risk assessment of copper-related compounds is currently being undertaken by a European manufacturers association and the results are scheduled to be published up to the end of 2011. Therefore, these results should be applied to all future assessments.

(6) Environmental risk assessment of other compounds leaching from the antifouling paints-applied hull surface

The environmental risks of compounds leaching from antifouling paints-applied hull surfaces, other than the abovementioned compounds, were assessed by similar exposure scenarios and methods, as summarized below.(For further details, see Reference-5)

a) Compounds assessed as no risk to environmental organisms

Three compounds, cuprous thiocyanate, IT354 and butyl thiram, were considered to have no effect on the environment, in terms of their current use, because the PEC/PNEC of these compounds was less than 1. However, since the only toxicity data on IT354 available were acute toxicity data for freshwater fish, the reliability of the PNEC might be low.

b) Compounds assessed as low risk to environmental organisms

The PEC/PNEC in Yokohama/Rotterdam Port for methyl thiram, ziram, tolyfluanid, dichlofluanid, chlorothalonil, zineb and “Sea-nine 211” was estimated to be at least 1. However, considering the current use of these compounds in painting products registered in Japan and other countries, they were considered to have only a low possibility of adversely affecting the environment.

c) Compounds to be noted in future use

The PEC/PNEC in Yokohama/Rotterdam Port for pyridine-triphenylborane (PK), diuron and irgarol exceeded 1 and, considering their actual use in paints, these compounds were not always considered to have a low impact on the environment. Consequently, these compounds should be noted or reviewed further, as described below.

- **Pyridine-triphenylborane (PK)**

  PK is quite commonly used in Japanese painting products while it is rarely used in such products in other countries. Therefore, considering its actual use in paints, the PEC/PNEC of PK was considered to have a potentially serious effect on the environment. One of the reasons why the PEC/PNEC of PK was so large was that the PNEC was underestimated in comparison with that of other antifouling compounds. While the acute toxicity value of PK used in this assessment was similar to that of other antifouling compounds, there was less toxicity data available on PK than for other compounds. Consequently, there is a possibility that the PNEC was underestimated (the toxicity was overestimated) with an assessment factor of 1,000. Since PK is relatively common in Japanese painting products and its use is expected to continue, more toxicity data (especially chronic toxicity data for marine organisms) should be accumulated in future and the PEC/PNEC should be assessed again on the basis of the updated data.

Although no international study has been carried out on PK concentrations in marine environments, the Japanese Ministry of Environment conducted an initial environmental survey in fiscal year 2003 and reported that PK concentrations were less than the detection limit (< 0.12 μg/L) at all 5 sampling points. Hiroshima City also conducted a survey from 2003 to 2004 and confirmed that PK concentrations were less than detection limit at all 9 sampling points, including marinas, fishery ports and environmental standard points.

• Diuron

Diuron is relatively common in Japanese and Australian painting products while it is rarely used in products manufactured in the United States and the United Kingdom. Existing toxicity data were readily available and the PNEC of diuron was estimated with an assessment factor of 50. Considering its actual use, therefore, diuron was considered to have a potentially serious effect on the environment. Thus, while painting products containing diuron had been registered in the United Kingdom, their registration was canceled in 2000. In Australia, the use of diuron for antifouling bottom paints is also being reassessed. Therefore, the use of diuron-containing paints should be reviewed in terms of both its environmental and biofouling effects, paying attention to the actions taken in other countries.

Several surveys have examined diuron concentrations in seawater. The UK Government has reported diuron concentrations ranging from <0.001 to 6.75 μg/L and from 0.016 to 1.25 μg/L at 36 points in ports and along the coast, including many ships and boats in 1998 and from 1999 to 2003. The New Zealand Ministry for the Environment conducted a survey in 2003 and found that the highest concentration of diuron was in a marina near Wellington with 0.25 μg/L. In Japan, a survey from 2002 to 2003 detected diuron concentrations exceeding the PNEC in the water at ports and along the coast. Diuron concentrations at 8 points in Osaka Port and surrounding areas ranged from <0.0007 to 1.54 μg/L.

• Irgarol

Irgarol is not commonly used in painting products in Japan and other countries, but the PEC/PNEC of irgarol in this assessment was much larger than that of other compounds. Irgarol was, therefore, considered to have some effect on the environment in terms of its current use conditions. The UK Government banned the use of irgarol-containing painting products on vessels under 25 m in length in 2000. Therefore, the use of irgarol-containing paints should be reviewed in terms of both its environmental and biofouling effects, paying attention to the actions taken in other countries.

Irgarol concentrations ranged from <0.001 to 1.42 μg/L and from 0.001 to 0.31 μg/L in the abovementioned UK surveys in 1998 and from 1999 to 2003, and ranged from <0.02 to 0.665 μg/L along Spain's Mediterranean coast in studies conducted from 1999 to 2000. In Japan, the abovementioned survey from 2002 to 2003 detected diuron concentrations exceeding the PNEC in the water in ports and along the coast. Diuron concentrations in Osaka Port and surrounding areas ranged from <0.0008 to 0.268 μg/L.

As described below, when treating complex components with a small application area (except hull outer skin), the PEC of the compounds used decreases in proportion to the area ratio. Therefore, if applied in accordance with the appropriate conditions, compounds which otherwise might cause concern about environmental risk when applied to the hull outer skin do not need to be immediately controlled or restricted.

5.2.2 Risks of compounds leaching from AFCS-processed ships

Antifouling paints used for the prevention of biofouling can also be applied to ship components other than the hull outer skin. In this assessment, antifouling paints are defined as a MGPS. However, the environmental risks of compounds leaching from antifouling paints applied to ship components other than the hull outer skin were assessed using similar procedures to those described in Section 5.2.1.

The PEC for each part of the ship was estimated on the basis of the PEC for Yokohama/Rotterdam Port, as described in Section 5.2.1, using the following procedures. The parts assessed included the outer hull plating, the sea chest, inner piping of the cooling water system, bilge keel, block-supported site, steering and other complicated parts.

(1) Estimation method for PEC (by ship part)

The procedures used for estimating the PEC (by ship part) were as follows:

- Standard areas for different ship parts for oil tankers, very large crude oil carriers (VLCC), colliers, panamax cargo ships, ore carriers, capesize, container ships and 6,000 TEU vessels were obtained from drawings and specifications provided by shipbuilders.
- A standard area ratio was estimated for each ship part for all types of ship.
- The PEC was calculated by multiplying the PEC for each of the 6 compounds found in Yokohama/Rotterdam Port (as calculated in the 2008 Report) by the area ratio for each ship part.

(2) Results of risk assessment (by ship part)

The PEC and PEC/PNEC (by ship part) for compounds leaching from antifouling paints-applied vessels are shown in Table 5.2-7～Table 5.2-10.

The results for the outer hull plating (accounting for 98% of the total hull area) were almost the same as the results for the total vessel, as shown in Section 5.2.1, and the PEC/PNEC of two compounds (pyrithione zinc and pyrithione copper) exceeded 1.

In contrast, the PEC/PNEC of all compounds on those parts of the ship with relatively small areas, compared to the outer hull plating, was less than 1 and the environmental risk was not considered to be of concern. Based on the above results, when carrying out risk assessment (by ship part), it can be seen that the risk depends on the area ratio of the part in question.

Table 5.2-7 PECs of active substance leached from ship's each area in Yokohama port

Chemical name	Max. Conc. in harbour (ng/L)						
	Outer hull	Sea chest	Cooling pipe	Bilge keel	Boad attaced area	rudder	Other area
Copper (I) oxide: Cu_2O*	2,342	7.2	4.8	4.8	16.7	9.6	4.8
Zinc pyrithione	53.4	0.16	0.11	0.11	0.38	0.22	0.11
Copper pyrithione	5.3	0.02	0.01	0.01	0.04	0.02	0.01
Total copper (dissolved form)	2,440	7.5	5.0	5.0	17.4	10.0	5.0
Total zinc (dissolved form)	55.2	0.17	0.11	0.11	0.39	0.23	0.11
TBT	88.10	0.27	0.18	0.18	0.63	0.36	0.18

*CuO is a reference data and not used for risk assessment

Table 5.2-8 PECs of active substance leached from ship's each area in Rotterdam port

Chemical name	Max. Conc. in harbour (ng/L)						
	Outer hull	Sea chest	Cooling pipe	Bilge keel	Boad attaced area	rudder	Other area
Copper (I) oxide: Cu_2O*	893	2.7	1.8	1.8	6.4	3.6	1.8
Zinc pyrithione	77.3	0.24	0.16	0.16	0.55	0.32	0.16
Copper pyrithione	6.8	0.02	0.01	0.01	0.05	0.03	0.01
Total copper (dissolved form)	1,146	3.5	2.3	2.3	8.2	4.7	2.3
Total zinc (dissolved form)	21.0	0.06	0.04	0.04	0.15	0.09	0.04
TBT	78.11	0.24	0.16	0.16	0.56	0.32	0.16

*CuO is a reference data and not used for risk assessment

Table 5.2-9 PEC/PNECs of active substance leached from ship's each area in Yokohama port

Chemical name	Outer hull	Sea chest	Cooling pipe	Bilge keel	Boad attaced area	rudder	Other area
Zinc pyrithione	4.9	0.01	0.01	0.01	0.03	0.02	0.01
Copper pyrithione	2.1	0.01	0.004	0.004	0.02	0.01	0.00
Total copper (dissolved form)	0.94	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Total zinc (dissolved form)	0.11	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
TBT	294	0.90	0.60	0.60	2.09	1.20	0.60

Table 5.2-10 PEC/PNECs of active substance leached from ship's each area in Rotterdam port

Chemical name	Outer hull	Sea chest	Cooling pipe	Bilge keel	Boad attaced area	rudder	Other area
Zinc pyrithione	7.0	0.02	0.01	0.01	0.05	0.03	0.01
Copper pyrithione	2.7	0.01	0.01	0.01	0.02	0.01	0.01
Total copper (dissolved form)	0.44	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Total zinc (dissolved form)	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
TBT	260	0.80	0.53	0.53	1.86	1.06	0.53

5.2.3 Risks of compounds released by in-water cleaning (IWC) of outer hull plating

(1) Risks during the IWC process

IWC is a removal technique which involves scraping biofouling from the outer hull plating, combined with the use of antifouling paint on hull bottoms. IWC is usually performed at intervals of several months to 2 years when vessels are anchored at sea. The usual means of carrying out IWC is to set up a cleaning device for the hull bottom and the outer plating using rotating cleaning brushes, i.e., physically scraping off the biofouling organisms. However, the brushes may simultaneously scrape off some of the paint on the bottom surface. Further details of

IWC can be found in Section 4.3. Several European countries and Australia have already highlighted the risk of harmful compounds being released, along with the increased risk of accidental transfer of organisms, and have considered introducing a IWC ban.

In this assessment, the risk of compounds in painted pieces scraped off the hull bottom by IWC and released into the surrounding water was investigated. A cleaning device for the outer hull plating that was referred to when setting the data on coated layer depth in this assessment involves fitting a net to catch all the pieces scraped off. The manufacturer explained that particles (≥0.5 mm) were caught and recovered by the net. However, the overall recovery rate of pieces scraped off the painted layer was unknown and the extent to which the recovery net may have reduced release was not considered in this assessment.

(2) Compounds to be assessed

A total of 6 compounds were assessed as major active substances leaching from antifouling paints -applied hulls. This included pyrithione zinc, pyrithione copper, total copper (copper as dissolved total copper) and total zinc (zinc as dissolved total zinc), and copper (I) oxide (for reference purposes) and a control TBT treatment.

(3) Establishment of exposure scenarios

As with the exposure scenarios for antifouling paints use described in Section 5.2.1, the following exposure scenario was established to estimate the PEC after IWC using the MAM-PEC model (ver. 2.5).

a) Estimation of IWC-processed hull bottom area

The hull bottom area of each ocean-going vessel was estimated from the mean weight (W_S) of ocean-going vessels arriving in Yokohama Port: W_S = 17,347 tons (OPRF, 2008) and the mean length of ship (L_S) using the following Froude equation:

$$\text{Ship hull bottom area of ocean going vessel } = W_S^{2/3} \times (3.4 + \frac{L_S}{2 \times W_S^{1/3}}) = 4{,}602\text{m}^2 / \mathit{vessel}$$

Where, the mean L_S was estimated to be 179 m, based on the equation: $L_S = (W_S / 0.003)1/3$

The total hull bottom area treated by IWC in Yokohama Port was calculated from the values estimated above, i.e., the hull bottom area of each ocean-going vessel, the number of vessels treated by IWC in Yokohama Port and the IWC-treated area of the hull bottom.

The number of vessels processed by IWC in Yokohama Port (N) was estimated in the following scenario: 12,937 vessels used for marine transportation around the world (the Ocean Policy Research Foundation (OPRF), 2009) were assumed to be processed by IWC every 2 years (6,468.5 times-IWC/year) and half of the ocean-going vessels arriving in Yokohama Port were assumed to be processed by IWC in Yokohama Port. The frequency of IWC in Yokohama Port was estimated to be 0.398 times-IWC/day by multiplying the frequency of IWC, worldwide, with the ratio of freight in Yokohama Port (OPRF, 2009) to marine freight movement (derived from international statistics on a pro-rata basis).

The percentage of IWC-treated area to the hull bottom area was set at 26.6%, based on the following information and settings:

- The ratio of the vertical part of the hull to the hull bottom area = 62:38 (based on the results of an interview survey of domestic shipbuilders).
- The percentage of IWC-treated area to the vertical part of the hull = 70% (the biofouling conditions are confirmed by divers during visual inspection and the amounts of biofouling organisms present are expected to be less in deep water).

IWC-treated area out of hull bottom area = 0.38 x 0.7 = 0.266

The total hull bottom area of IWC-treated vessels in Yokohama Port ($A_{\text{IWC-total}}$) was calculated from the above parameters using the following equation:

$$A_{IWC-total} = N_{IWC} \times A_{IWC-S} = 0.398 \times (4{,}595 \times 0.266) = 487\ m^2 / day$$

Where,

$A_{\text{IWC-total}}$: total hull bottom area treated by IWC per day (m^2/day)
N_{IWC}: the number of vessels treated by IWC (vessel/day)
$A_{\text{IWC-S}}$: the hull bottom area treated by IWC per vessel (m^2)

The total hull bottom area, which was calculated using the hull bottom area per vessel estimated in accordance with the above scenario and the number of ocean-going vessels arriving in Yokohama Port (11,016 vessels/year, OPRF 2008), was 138,877 m^2/day, similar to the figure of 129,959 m^2 cited in the 2008 report.

b) Estimation of releases of compounds from the IWC process

The full risk assessment carried out by AIST confirmed that the lowest and highest contents of pyrithione copper in antifouling paints were 1.45 and 3.66 wt%, respectively, and the density of pyrithione copper-containing antifouling paints was 1.69 g/cm^3 (AIST, 2004).

Since IWC is currently implemented at 2-year intervals, on average, macro biofouling is probably severe on some ship components. In actual IWC, divers select brushes corresponding to the severity of macro biofouling. Therefore, it was assumed that the thickness of painted pieces scraped off by IWC was 100 μm (over 95% of the IWC-treated area) and 500 μm in the worst case (over 5% of the IWC-treated area). The percentage of compounds remaining in a painted piece scraped off by IWC was assumed to be only 10% because the compounds in that layer, from the surface to 100 μm in depth, were considered to have almost completely leached out before then. The percentage of compounds remaining in a 500-μm painted piece scraped off by IWC was assumed to be 82% because the concentration of compounds in a layer of 100 μm or more in depth was not considered to have decreased significantly from the initial concentration in the antifouling paint when first applied.

In the above scenario, the amount of pyrithione copper released by IWC in Yokohama Port ($E_{\text{IWC-CuPT}}$) was calculated using the equation shown below, where the $A_{\text{IWC-total}}$ was 487 m^2/day (based on the result from Section a). Since the solvent content in antifouling paint was assumed to be 50%, the volume of painted film after drying (per unit area) was 50% of the volume of paint originally applied to the ship surface. Consequently, the volume of paint on the ship surface was estimated to be 50% of the original volume of paint applied.

$$E_{IWC-CuPt} = 487 \times (100 \times 1.69 \times 0.0366 \times 0.95 \times 0.1 + 500 \times 1.69 \times 0.0366 \times 0.05 \times 0.82) \times 2 = 1{,}808 \text{ g/day}$$

= Release of pyrithione copper in Yokohama Port

In the estimation of all compounds except pyrithione copper, neither the content of the compounds in the antifouling paint nor theamount of paint scraped off by IWC was unknown, therefore, the content of compounds in painted pieces scraped off was assumed to be 5 wt% in the worst case and the amount of scraped off was assumed to be 1.69 g/cm^3 (the same as that for pyrithione copper).

$$E_{IWC-AS} = E_{IWC-CuPT} \times \frac{5}{3.66} = 2{,}470 g / day$$

= Release of active substances (except pyrithione copper) in Yokohama Port

In the estimation carried out for Rotterdam Port, since statistical data were not available the PEC was estimated on the assumption that the release in Rotterdam Port was 7.7 times greater than that in Yokohama Port (similar to the results found in the 2008 report). Consequently, the releases of pyrithione copper and other active substances were estimated as follows:

Release of pyrithione copper in Rotterdam Port: 13,923 g/day
Release of active substances (except pyrithione copper) in Rotterdam Port: 19,020 g/day

The amount of paint pieces scraped off by IWC was estimated from the IWC-treated area per day and the amount (g/day) of compounds released per day was estimated from the percentage of compounds remaining in the painted pieces. In this scenario, all release of compounds from the painted pieces scraped off into the surrounding sea area was assumed to occur on the day of IWC application (immediately after IWC implementation). However, in actual environments, compounds leach out from the surface of painted pieces scraped off by IWC in accordance with the leaching rate. Therefore, the amount of compounds released into the seawater may be overestimated if the compounds do not completely leach out from the painted pieces scraped off by IWC but accumulate in sediments instead.

It is also expected that the form and content (5) of compounds in the painted surface will differ significantly depending on the type of antifouling paint used. In the exposure scenario used in this survey, the worst case of a common self-polishing antifouling paint was estimated from the information available. Therefore, further assumption, it will be necessary to collect further data from comprehensive studies and analyses and review the parameters used in this assessment. Furthermore, it will also be necessary to develop a mathematical model for PEC estimation, taking the form of compounds found after leaching into the environment and the environmental fate of these compounds into consideration.

The content of the exposure scenario used for IWC, described above, and the estimated amount of active substances leaching into the environment are shown in Tables 5.2.11 and 5.2.12.

Table 5.2-11 Emission scenario and its parameters of IWC under currently in use

Parameter	Bio-coverage		Rationale
	Slight	Heavy	
Hull bottom area per vessel (m^2/vessel)	4,602		Calculated by the Froude equation
Ratio of the vertical part in the hull area (%)	38		According to the survey, bottom/ vertical part in the hull area is ca 62/38.
Ratio of IWC in the vertical part of the hull area (%)	70		IWC is only applied where biofouling is visually confirmed by divers (assumed to be 70%).
Ratio of IWC area in the hull area (%)	26.6		Obtained from ratio of vertical part and IWC application area
IWC application area per vessel (m^2/vessel)	1,224		Obtained from the hull bottom area and IWC application area
Frequency of IWC (times/year/ship)	0.5		Under current scenario, IWC is only applied when heavy biofouling is confirmed, i.e. every two years.
Frequency of IWC applied vessels in Yokohama-port (times-IWC/ ship-Yokohama)	0.5		Since only limited ports can conduct IWC other than Yokohama, it is assumed that half number of vessels arrive in Yokohama is carried out IWC.
Daily number of IWC in Yokohama-port (times-IWC/day/Yokohama)	0.398		Obtained from global number of ocean-going vessels and cargo volumes in Yokohama IWC is done every two year.
Daily IWC total area (m^2/day/Yokohama)	487		Obtained from IWC area per vessel and daily number of IWC.
Thickness of removed paint chips (μm)	100	500	Assumed that biofouling is slight in 95% of area and used soft brush (100 μm) but heavy in 5% and used hard brush (500 μm) for IWC.
Ratio of each paint chips (%)	95	5	
Density of removed paint chip (g/m^3)	1.69		According to AIST Initial Risk Assessment (pyrithione copper)
Contents in AFCS (wt-%) (pyrithione copper)	3.66		According to AIST Initial Risk Assessment (pyrithione copper)
Contents in AFCS (wt-%) (other than pyrithione copper)	5		Worst case is used since no information is available.
Remainging part of active substance in paint chips when IWC is done (%)	10	82	Assumed that contents of remaining active substance in removed paint chips are 10% (in 100μm of chips) and 82% (in 500 μm of chips).
Non volatile part of paints (%)	50		Assumed that content of volatile solvents in original paint is 50%.

Table 5.2-12 Emission rate of active substance due to IWC under currently in use

	Emission rate (g/day)		Total emission rate (g/day)	Rationale
	Coverage of biofouling			
	Slight	Heavy		
Yokohama-port, CuPt	573	1,236	1,808	Daily emission rate of active substance due to IWC in Yokohama port
Yokohama-port, other thanCuPt	782	1,688	2,470	
Rotterdam port, CuPt	4,409	9,514	13,923	Daily emission rate of active substance due to IWC in Rotterdam port
Rotterdam port, other than CuPt	6,023	12,997	19,020	

CuPt: Pyrithione copper

(4) Parameters for PEC estimation using the MAM-PEC model

Environmental conditions of a model port and the physicochemical properties and environmental fate data of compounds used for PEC estimation with the MAM-PEC model were equivalent to those used for the AFCS process (see Table 5.1-1、Table 5.1-2).

(5) PEC estimation results for compounds released during the IWC process

The PEC for the IWC process in the abovementioned exposure scenario was estimated using the MAM-PEC model (ver. 2.5).

Table 5.2-13 PECs of chemical substance in Yokohama port due to IWC currently in use

Chemical name	PEC in harbour (ng/L)		PEC in surroundings (ng/L)	
	Max	Min	Max	Min
Copper oxide	114	70.4	2.97	0.88
Pyrithione zinc	22.6	9.09	0.22	0.07
Pyrithione copper	2.59	0.40	2.93E-05	7.83E-06
Total copper (dissolved)	114	70.4	2.97	0.88
Total zinc (Dissolved)	114	70.4	2.97	0.88
TBT	89.9	54.7	2.26	0.70

Table 5.2-14 PECs of chemical substance in Rotterdam port due to IWC currently in use

Chemical name	PEC in harbour (ng/L)		PEC in surroundings (ng/L)	
	Max	Min	Max	Min
Copper oxide	43.4	24.1	1.69	0.88
Pyrithione zinc	32.9	13.3	0.56	0.29
Pyrithione copper	3.37	0.51	4.67E-05	2.13E-05
Total copper (dissolved)	43.4	24.1	1.69	0.88
Total zinc (Dissolved)	43.4	24.1	1.69	0.88
TBT	80.0	43.8	3.04	1.58

In the exposure scenarios used in this assessment, the PEC was estimated based on the assumption that releases of all compounds (except pyrithione zinc) were equivalent. Consequently, the PEC of nondegradable (very slowly degradable) copper (I) oxide, total copper and total zinc were also estimated to be equivalent.

The PEC of copper (I) oxide, total copper and total zinc in Yokohama Port was estimated using the MAM-PEC model and the highest and the mean concentrations for all of these substances in the harbour were 114 and 70.4 ng/L, respectively. The PEC of pyrithione zinc in Yokohama Port was estimated and the highest and mean concentrations in the harbour were 22.6 and 9.09 ng/L, respectively. In contrast, the highest and mean concentrations of pyrithione copper were only 2.59 and 0.40 ng/L, respectively.

The PEC of copper (I) oxide, total copper and total zinc in Rotterdam Port was estimated and the highest and mean concentrations in the harbour were 43.4 and 24.1 ng/L, respectively. During the estimation of the PEC for pyrithione zinc and pyrithione copper, the highest concentrations in the harbour were 32.9 and 3.37 ng/L and the mean concentrations in the harbour were 13.3 and 0.51 ng/L, respectively.

Although it is difficult to make simple comparisons using the above data, the PEC of pyrithione copper in Tokyo Bay was estimated during the full risk assessment carried out by AIST (AIST, 2004). In the above assessment, it was assumed that TBT in antifouling paints used for hull bottoms was completely replaced with pyrithione copper and the PEC was estimated from the content of pyrithione copper in paint (3.66 wt%) and the density of paint (1.69 g/cm^3) using the abrasion speed of the paint. The leaching rate of pyrithione copper used for PEC estimation was 1.6 µg/cm^2/day. Consequently, the PEC in Tokyo Bay was estimated to be 7–96 ng/L.

In the abovementioned scenario where pyrithione copper leached from the antifouling paints process, as shown in Section 5.2.1, the PEC (the highest concentration in water in a port) was estimated to be 5.37 ng/L. Consequently, the total PEC of pyrithione copper from IWC implementation and leaching from antifouling paints in Yokohama Port was 8.74 ng/L - close to the PEC range estimated by AIST. In the PEC estimation carried out by AIST, the total amount of pyrithione copper leaching from hulls and facilities in the port was used.

5.2.4 Environmental risks of the total PEC of compounds leaching from antifouling paints-applied hulls and compounds released by the IWC process

(1) Results of risk assessment for the IWC process (PEC/PNEC)

The PEC$_{IWC}$/PNEC in Yokohama and Rotterdam Port was calculated using the PEC$_{IWC}$ estimated above and is shown in the following tables.

Table 5.2-15 PEC/PNECs of chemical substance in Yokohama port due to IWC currently in use

Chemical name	PEC/PNECs in harbour (ng/L)		PEC/PNECs in surroundings (ng/L)	
	Max	Min	Max	Min
Pyrithione zinc	2.1	0.83	0.020	< 0.01
Pyrithione copper	1.04	0.16	< 0.01	< 0.01
Total copper (dissolved)	0.044	0.027	< 0.01	< 0.01
Total zinc (Dissolved)	0.22	0.14	< 0.01	< 0.01
TBT	333	202	8.4	2.6

Table 5.2-16 PEC/PNECs of chemical substance in Rotterdam port due to IWC currently in use

Chemical name	PEC/PNECs in harbour (ng/L)		PEC/PNECs in surroundings (ng/L)	
	Max	Min	Max	Min
Pyrithione zinc	3.0	1.20	0.051	0.026
Pyrithione copper	1.3	0.20	< 0.01	< 0.01
Total copper (dissolved)	0.017	< 0.01	< 0.01	< 0.01
Total zinc (Dissolved)	0.084	0.046	< 0.01	< 0.01
TBT	296	162	11.3	5.8

(2) Risk assessment of the total PEC of compounds leaching from both the IWC process and antifouling paints use

The PEC_{AFCS} from AFCS use that was estimated in Section 5.2.1 and the PEC_{IWC} from the IWC process were combined as PEC_{total} and the risk assessment carried out using PEC_{total} and the contribution rate of IWC are shown below.

Table 5.2-17 PEC_{total} of chemical substance in Yokohama port

Chemical name	PEC_{total} in harbour (ng/L)		PEC_{total} in surroundings (ng/L)	
	Max	Min	Max	Min
Copper oxide	2,504	1,550	65.6	20.4
Pyrithione zinc	77.1	31.0	0.75	0.23
Pyrithione copper	8.0	1.2	9.0E-05	2.4E-05
Total copper (dissolved)	2,604	1,750	419	379
Total zinc (Dissolved)	170	105.3	4.4	1.3
TBT	180	109.3	4.5	1.4

Table 5.2-18 PEC_{total} of chemical substance in Rotterum port

Chemical name	PEC_{total} in harbour (ng/L)		PEC_{total} in surroundings (ng/L)	
	Max	Min	Max	Min
Copper oxide	954	529	37.2	19.3
Pyrithione zinc	112	45.0	1.9	0.99
Pyrithione copper	10.3	1.6	1.4E-04	6.5E-05
Total copper (dissolved)	1,212	832	394	377
Total zinc (Dissolved)	64.8	36.0	2.5	1.3
TBT	160	87.4	6.1	3.1

Table 5.2-19 PEC$_{total}$/PNECs of chemical substance in Yokohama

Chemical name	PEC/PNECs in harbour (ng/L)		PEC/PNECs in surroundings (ng/L)	
	Max	Min	Max	Min
Pyrithione zinc	7.0	2.8	0.068	0.021
Pyrithione copper	3.2	0.49	< 0.01	< 0.01
Total copper (dissolved)	1.001	0.67	0.16	0.15
Total zinc (Dissolved)	0.33	0.20	< 0.01	< 0.01
TBT	666	405	16.7	5.2

Table 5.2-20 PEC$_{total}$/PNECs of chemical substance in Rotterdam port

Chemical name	PEC/PNECs in harbour (ng/L)		PEC/PNECs in surroundings (ng/L)	
	Max	Min	Max	Min
Pyrithione zinc	10.2	4.1	0.17	0.090
Pyrithione copper	4.1	0.62	< 0.01	< 0.01
Total copper (dissolved)	0.47	0.32	0.15	0.14
Total zinc (Dissolved)	0.12	0.069	< 0.01	< 0.01
TBT	592	324	22.5	11.7

Table 5.2-21 Contribution* of IWC in PEC$_{total}$ of chemical substance in Yokohama port

Chemical name	PEC$_{total}$ in harbour (ng/L)		PEC$_{total}$ in surroundings (ng/L)	
	Max	Min	Max	Min
Copper oxide	4.5	4.5	4.5	4.3
Pyrithione zinc	29.3	29.3	29.3	29.3
Pyrithione copper	32.5	32.5	32.6	32.6
Total copper (dissolved)	4.4	4.0	0.7	0.2
Total zinc (Dissolved)	66.9	66.9	66.9	65.9
TBT	50.0	50.0	50.0	50.0

*: PEC$_{IWC}$/PEC$_{(AFCS+IWC)}$

Table 5.2-22 Contribution* of IWC in PEC$_{total}$ of chemical substance in Rotterdam port

Chemical name	PEC$_{total}$ in harbour (ng/L)		PEC$_{total}$ in surroundings (ng/L)	
	Max	Min	Max	Min
Copper oxide	4.5	4.6	4.5	4.6
Pyrithione zinc	29.5	29.5	29.4	29.5
Pyrithione copper	32.7	32.6	32.6	32.6
Total copper (dissolved)	3.6	2.9	0.4	0.2
Total zinc (Dissolved)	67.0	67.0	66.8	67.1
TBT	50.1	50.1	50.1	50.1

*: PEC$_{IWC}$/PEC$_{(AFCS+IWC)}$

In the risk assessment carried out with the PEC estimated only from the IWC process in Yokohama Port, the PEC/PNEC of pyrithione zinc at the highest concentration in the port was 2.1. The PEC/PNEC of all active substances (except pyrithione zinc and pyrithione copper) was less than 1.

In the risk assessment carried out with the total PEC of compounds from IWC implementation and leaching from antifouling paints in Yokohama Port, the PEC/PNEC of pyrithione zinc, at the highest concentration, was estimated to be 7.0 and that of pyrithione copper was estimated to be 1 or more.

In the risk assessment carried out with the PEC estimated only from the IWC process in Rotterdam Port, the PEC/PNEC of pyrithione zinc and pyrithione copper was 1 or more.

The PEC/PNEC of total copper and total zinc in Yokohama Port (at all concentrations except the maximum value) was less than 1.

In the risk assessment with the total PEC, estimated from both IWC implementation and leaching from antifouling paint in Rotterdam Port, the PEC/PNEC of pyrithione zinc and pyrithione copper was estimated to be 1 or more and the PEC/PNEC of pyrithione zinc, at the highest concentration in port, was 10.2 (the highest of all the PEC/PNECs).

The contribution rate of IWC implementation to the total PEC estimated from both IWC implementation and leaching from antifouling paint depended on the leaching rate of compounds. The contribution rate of total zinc was the highest, at approximately 67%, while that of copper (I) oxide and total copper was the lowest, at 3-5%.

Consequently, the PEC/PNEC of pyrithione zinc estimated only from the IWC process exceeded 1. However, it is difficult to conclude that the environmental risk posed by IWC is of immediate concern.

In the scenario used in this assessment, the content of compounds in antifouling paint pieces scraped off by IWC was assumed to be 5 wt% and the amount of AFCS pieces scraped off was assumed to be 1.69 g/cm^3 since no measurement data were available for any compounds except pyrithione copper. Furthermore, since scraped-off pieces will, in future, be collected using a recovery net during the IWC process, some or most of the painted pieces scraped off by IWC will be recovered. Consequently, releases of compounds into the surrounding sea area will be reduced. The use of softer brushes than those currently used in the IWC process could also reduce the amount of painted pieces scraped off.

As mentioned above, in the risk assessments based on total PEC, estimated from both IWC implementation and leaching from antifouling paint, the highest PEC/PNEC was 10.2 for pyrithione zinc in Rotterdam Port. Considering that the contribution rate of the IWC process was less than 30%, the likelihood of pyrithione zinc from the increased use of IWC posing a risk to environmental organisms is probably limited. In other words, considering the current frequency of IWC use and the area affected, and the hardness of the brushes used in the IWC process, it is not necessary to be excessively concerned about IWC use and the associated environmental risks.

TBT was also included for reference purposes and the PEC/PNEC estimated only from the IWC process was 333 in Yokohama Port and 296 in Rotterdam Port. In the risk assessment based on total PEC, estimated from both IWC implementation and leaching from antifouling paint, the highest PEC/PNEC value estimated was 666. This result suggests that environmental risks are a concern even if extremely few vessels (one in several hundred) undergoing the IWC process in this scenario use TBT-containing antifouling paints. Under the terms of the International Convention on the Control of Harmful Anti-fouling Systems on Ships (the AFS Convention), signatory countries have prohibited the use of antifouling paints containing organotin since 2008. However, it is assumed that small vessels and some other vessels still use antifouling paints containing TBT. Vessels that have already been treated with TBT-containing antifouling paint may still be in operation. Therefore, IWC should not be carried out on vessels processed with antifouling paints containing TBT.

In the risk assessment based on total PEC, estimated from both current IWC implementation and leaching from antifouling paint, the PEC/PNEC of pyrithione zinc and pyrithione copper exceeded 1 but that of all other compounds was less than 1. The largest and smallest increases in environmental risk due to IWC were 67% for zinc and approximately 3-5% for copper (I) oxide and total copper. The PEC of compounds leaching from antifouling paints depends on the leaching rate. However, the scenario used in this assessment assumed that all the compounds in the painted pieces scraped off by IWC were released into the environment immediately. Consequently, the contribution rate of IWC to the total PEC was higher in compounds with a lower leaching rate.

In the exposure scenario used in this assessment, the PEC could be overestimated in the worst-case scenario because measurement data were not available. The possible factors contributing to this overestimation are shown below:

- The recovery of painted pieces by the recovery net used in IWC process have not been calculated.
- Some of the compounds found in the painted pieces scraped off by IWC have already been leached from the surface. Therefore, the content of compounds is probably less than the initial concentration. In addition, the content of pyrithione copper was established to be 3.66 wt%, the highest initial concentration, while that of other active substances was set at 5 wt% due to the lack of available data in this assessment.

Consequently, it might be premature to immediately conclude that pyrithione zinc, pyrithione copper and total copper with $PEC/PNEC \geq 1$ in this assessment (based only on the total of IWC implementation and leaching from antifouling paint) pose unacceptable levels of environmental risk. If painted pieces can be collected with a net, the risk of IWC implementation to the ecosystem in the surrounding environment can be reduced to an acceptable level in the scenario established for this survey. Furthermore, any improvement in brushes used for IWC in the future could further reduce the amount of painted pieces scraped off by IWC and the amounts of compounds released in them.

Further accurate risk assessment requires additional information on the content of compounds in the painted pieces scraped off by the IWC process, and the size, shape and density of the painted pieces scraped off and released. Furthermore, additional data are also needed on the effectiveness of the recovery net and improved brushes in reducing the release of such compounds.

5.2.5 Risk assessment for the use of seawater electrolysis systems in scenarios based on the current technique (applying 0.3 mg/L of chlorine compound to the inner piping of the cooling water system)

The seawater electrolysis system, a leading MGPS, electrolytically generates chlorine compounds (mainly chlorine compounds containing hypochlorite ions) which can be detected as residual chlorine in seawater, and uses chlorine compounds as its active substances. The mechanism used for antifouling involves continuously injecting chlorine compounds, electrolytically generated from seawater, into the cooling water, etc. in order to prevent biofouling. In this study, the risks posed by chlorine compounds in the form of residual chlorine and byproducts to aquatic organisms were assessed on the basis of information on the operating conditions for seawater electrolysis systems currently in use.

(1) Establishment of exposure scenarios

a) Model ports

The PEC of chlorine compounds detected as residual chlorine and byproducts using Yokohama/Rotterdam Port as a model port was estimated in a similar manner to the abovementioned exposure scenarios for antifouling paints use.

b) Operating conditions for seawater electrolysis systems and scenario used for the emission of chlorine compounds

Domestic manufacturers/distributors of seawater electrolysis systems provided information showing that the concentration of residual chlorine immediately after injecting chlorine compounds into the cooling water ranged from 0.15 to 0.3 mg/L. When used for seawater cooling systems (piping), chlorine compounds are released from vessels along with the seawater cooling water several seconds to tens of seconds after injecting seawater electrolyte.

Chlorine compounds in seawater electrolyte, which can be analyzed as residual chlorine, start to degrade as soon as they enter the cooling seawater. However, the actual degradation rate depends largely on the temperature and the pH of the cooling water, light, the presence of metal ions and organic compounds in the water, and other conditions. Therefore, the concentration of residual chlorine upon release (immediately after being released from vessels), as required for PEC estimation, was set at 0.3 mg/L, after considering actual concentrations at the time of injection.

Since the cooling water volume (release volume) differs significantly depending on the vessel size and its activities, it is difficult to establish a standard volume. The cooling water volume is sometimes controlled by changing the device power setting, depending whether the vessel is at sea or in the harbour. Therefore, in the scenario used for this study, considering the operating conditions for the seawater electrolysis system provided by domestic shipbuilders, the usual cooling water volume used during loading was assumed to be 84 m^3/h/vessel, compared to only 21 m^3/h/vessel (one fourth of the regular volume) at other times. The ratio of the loading period to the unloading period was estimated from the gross tonnage figures for ocean-going vessels arriving in Yokohama Port (by vessel type and mooring time) provided by the “Research Report of Environmental Effects of Vessel-oriented Particle Material (PM) (OPRF 2008)”.

The release volume during loading and unloading, per day, for several different types of vessel was estimated first and then multiplied by the release ratio based on the gross tonnage in order to calculate the cooling water volume released by each vessel. Based on the above results, the release volume of cooling water containing residual chlorine in Yokohama Port was estimated to be 966 m^3/day/vessel (=40.2 m^3/h/vessel). Consequently, based on the assumption that all vessels arriving in Yokohama Port (11,016 ocean-going vessel arrivals/year according to the Port and Harbour Bureau of Yokohama City, 2009) use the seawater electrolysis system, the total release volume of cooling water from the seawater electrolysis systems was estimated to be 29,152 m^3/day. In the estimation carried out for Rotterdam Port, since statistical data were not available the release volume was estimated to be 224,471 m^3/day, based on the assumption that the release volume in Rotterdam Port was 7.7 times greater than that in Yokohama Port (similar to the figures given in the 2008 report).

(2) Identification of byproducts

It has been confirmed that byproducts such as trihalomethane are generated by the reaction between residual chlorine compounds in the seawater electrolyte and organic carbon compounds in the cooling water used in the seawater electrolysis system for seawater cooling systems. However, no data were available on the generation of such byproducts in the use of the seawater electrolysis system during this study. Therefore, the byproducts to be assessed were selected from those generated when chlorine compounds in the electrolysis device were used as active substances for ballast water management systems (BWMS) and the highest detected concentrations of byproducts were used as the release concentrations (Table 5.2-23). When selecting the byproducts to be assessed, those whose highest detected concentration was less than 10 μg/L (except for chloroform) were excluded because their risk was considered to be low. Consequently, only 7 byproducts (bromoform, chloroform, dibromochloromethane, monobromoacetic acid, dibromoacetic acid, tribromoacetic acid and chloramine/bromoamine) were assessed.

Table 5.2-23 By-products and maximum detected concentrations (MDC) in ballast water management systems

By-products	MDC (μg/L)	Initial chlorine concentration (mg TRO/L as Cl_2)	BWMS (system name/ country/MEPC*)	Main active substance(s)
Bromoform	480	10	Electro-Clean System/the Republic of Korea/MEPC58	Hypochlorous acid (HOCl) Hypobromous acid (HOBr) Ozone (O_3) (generated by electrolysis module)
Chloroform	0.13			
Dibromochloromethane	14			
Monobromo acetic acid	26			
Dibromo acetic acid	271			
Tribromo acetic acid	183			
Chloramine/ Bromamine	410 (non neutralisation)	9.5	Sunrui Ballast Water Management System/China/MEPC60	Hypochlorous acid (HOCl) Hypobromous acid (HOBr) Chloramines/ Bromamines (generated during electrolysis)

* MEPC: Marine Environment Protection Committee

(3) Estimation of release amounts

Since no measurement data were available on byproducts found under the operating conditions of seawater electrolysis systems in vessels, the highest concentrations detected in the BWMS, as shown in Table 5.2-23, were used as the concentrations of the byproducts released. The release amount (g/day) of each chlorine compound was estimated from the release volume of cooling water in the abovementioned scenario and the injection concentration (0.3 mg/L) was used as the release concentration in the worst case. The estimated release amounts of chlorine compounds and byproducts are shown in Table 5.2-24. Since the retention time from injection to release and the concentrations of chlorine compounds in ballast water management systems are different from those found when the seawater electrolysis system is used for cooling water, the concentrations of byproducts produced can also be expected to be different.

Table 5.2-24 Estimated emission volume of chlorine compound and by-products in Yokohama and Rotteram port (g/day)

Chemical name	Yokohama	Rotterdam
Chlorine compound (0.3 mg/L)	8,746	67,341
Bromoform	13,993	107,746
Chloroform	3.79	29
Dibromochloromethane	408	3,143
Monobromo acetic acid	758	5,836
Dibromo acetic acid	7,900	60,832
Tribromo acetic acid	5,335	41,078
Chloramine/ Bromamine	11,952	92,033

(4) Estimation of PEC

a) Simulation model for PEC estimation

Similarly to the above estimation of PEC in AFCS use, the PEC of chlorine compounds and byproducts was estimated using the updated MAM-PEC model ver. 2.5 (October 2008).

b) Environmental parameters used in the MAM-PEC model

The parameters described in Section 5.2.1 were used as the environmental parameters in Yokohama/Rotterdam Port to estimate the PEC using the MAM-PEC model (see Table 5.1-1).

c) Physicochemical properties and environmental fate of compounds to be assessed

Physicochemical properties and environmental fate data of chlorine compounds (residual chlorine) and byproducts are shown below. The data were obtained from the relevant databases (PhysProp Database, etc.) wherever possible while data on some other parameters not available elsewhere were obtained from the calculation results of Quantitative Structure-Activity Relationships (QSARs) using EPI Suite.

Since detailed information concerning the identification and concentration of compounds could not be confirmed in the BMWS review data and since data on halogenated amines (except monochloramine) were not available, in this study the PEC was estimated based on the assumption that monochloramine was a typical halogenated amine.

Table 5.2-25 Physico-chemical properties and environmental fate of chlorine compound and by-products (1)

CAS number		7681-52-9	75-25-2	67-66-3	124-48-1
Chemical name		Chlorine compound (NaClO)	Bromoform	Chloroform	Dibromochloromethane
Molecular weight (g/mol)		74.4	252.77	119.38	208.28
Vapour pressure (Pa)		1.03E-13 [*1]	7.20E+02	2.63E+04	1.01E+04
Sol. In wat. (g/m^3)		2.93E+05	3.1E+03	7.95E+03	2.7E+03
Deg. rate (1/day)	abiotic: water	0	0	0	0
	abiotic: sediment	0	0	0	0
	Photolysis: water	8.35	0	0	0
	Photolysis: sediment	0	0	0	0
	Biodeg: water	0	0	0	0
	Biodeg: sediment	0	0	0	0
log Kow		-3.42 [*1]	2.38	1.97	2.16
log Koc		1.155 [*1]	1.544 [*1]	1.53	1.544
Henry constant (Pa-m^3/mol)		1.02E-15[*1]	5.42E+01	3.72E+02	1.00E+02
Melting point (ºC)		-20	8	-64	-20

Table 5.2-26 Physico-chemical properties and environmental fate of chlorine compound and by-products (2)

CAS number		79-08-3	631-64-1	75-96-7	10599-90-3
Chemical name		Monobromo acetic acid	Dibromo acetic acid	Tribromo acetic acid	Chloramine
Molecular weight (g/mol)		138.95	217.84	296.74	51.48
Vapour pressure (Pa)		15.8	3.07	0.0372	1.54E-07[*1]
Sol. In wat. (g/m^3)		1.75E+06	2.11E+06	2.00E+05	1.00E+06[*1]
Deg. rate (1/day)	abiotic: water	0	0	0	0
	abiotic: sediment	0	0	0	0
	Photolysis: water	0	0	0	0
	Photolysis: sediment	0	0	0	0
	Biodeg: water	0	0	0	0
	Biodeg: sediment	0	0	0	0
log Kow		0.41	0.7	1.71	-1.19[*1]
log Koc		0.0794[*1]	0.2775[*1]	0.4374 [*1]	1.1553[*1]
Henry constant (Pa-m^3/mol)		6.60E-04	4.48E-04	3.30E-04	6.72 [*1]
Melting point (ºC)		50	49	129-135	-66

References: ATSDR (2005), EU (2007b), SRC (2009), U.S. NLM (2009)

[*1]: Estimated by a QSAR model (US-EPA, EPI-SUITE)

(5) Estimation results of PEC

The PECs of chlorine compounds and byproducts in Yokohama/Rotterdam Port (the highest and mean concentration in the harbour and surrounding water area) that were estimated by the MAM-PEC model in the abovementioned scenario are shown below.

The highest PEC of chlorine compounds in the harbour was 0.0329 μg/L in Yokohama Port and 0.0429 μg/L in Rotterdam Port.

Table 5.2-27 PECs of chlorine compounds and by-products in Yokohama port

Chemical name	In harbour PEC (μg/L)		Surrounding PEC (μg/L)	
	Max.	Average	Max.	Average
Chlorine compound (0.3 mg/L)	0.0329	7.83E-03	3.59E-05	1.09E-05
Bromoform	0.473	0.283	0.0116	3.60E-03
Chloroform	1.01E-04	5.81E-05	2.29E-06	7.16E-07
Dibromochloromethane	0.0128	7.57E-03	3.06E-04	9.56E-05
Monobromo acetic acid	0.0365	0.0226	9.54E-04	2.97E-04
Dibromo acetic acid	0.380	0.236	9.95E-03	3.09E-03
Tribromo acetic acid	0.257	0.159	6.72E-03	2.09E-03
Chloramine/ Bromamine	0.448	0.271	0.0112	3.49E-03

Table 5.2-28 PECs of chlorine compounds and by-products in Rotterdam port

Chemical name	In harbour PEC (μg/L)		Surrounding PEC (μg/L)	
	Max.	Average	Max.	Average
Chlorine compound (0.3 mg/L)	0.0429	0.01	6.69E-05	3.36E-05
Bromoform	0.473	0.259	0.0179	9.29E-03
Chloroform	1.16E-04	6.24E-05	4.22E-06	2.19E-06
Dibromochloromethane	0.0134	7.31E-03	5.03E-04	2.61E-04
Monobromo acetic acid	0.0284	0.0158	1.13E-03	5.84E-04
Dibromo acetic acid	0.296	0.165	0.0117	6.09E-03
Tribromo acetic acid	0.2	0.111	7.92E-03	4.11E-03
Chloramine/ Bromamine	0.418	0.23	0.0161	8.33E-03

(6) Estimation of PNEC

Toxicity data were collected and compiled for chlorine compounds and byproducts used for PNEC estimation by means of the assessment method for chemical environmental risks, as described in Section 5.1. The compiled data are shown in Reference-6. The lowest toxicity value (NOEC or LC/EC$_{50}$) for each compound was selected from the obtained data and the PNEC of chlorine compounds and byproducts was estimated by dividing the lowest toxicity value by an assessment factor.

The PNEC of chlorine compounds was estimated to be 0.8 µg/L by dividing a 28-day NOEC in marine fish (40 µg/L) by an assessment factor (50).

Table 5.2-29 PNECs of chlorine compound and by-products

Chemical name	Species	Endpoint	NOEC (µg/L)	Assessment factor	PNEC (µg/L)
Chlorine compound (NaClO)	Tidewater silverside (*Menidia peninsulae*)	28-d NOEC	40	50	0.8
Bromoform	Sheepshead minnow (*Cyprinodon variegates)*	28-d MATC	4,800	50	96
Chloroform	Japanese killifish (*Oryzias latipes*)	6/9 months NOEC	1,463	10	146
Dibromochloromethane	Water flea (*Daphnia magna*)	21-d NOEC	63	50	1.26
Monobromo acetic acid	Green algae (*Scenedesmus subspicatus*)	72-hr EC$_{50}$	1,400	1,000	1.4
Dibromo acetic acid	Fathead minnow (*Pimephales promelas*)	96-hr LC$_{50}$	69,000	10,000	6.9
Tribromo acetic acid	—	—	—	—	—
Chloramine/ Bromamine	Water flea (*Daphnia magna*)	24-hr LC$_{50}$	11	1,000	0.011

(7) Results of risk assessment (PEC/PNEC)

The results of risk assessment (PEC/PNEC) for chlorine compounds and byproducts from the use of the seawater electrolysis system for seawater cooling systems (piping) in Yokohama/Rotterdam Port are shown below.

The PEC/PNEC of chlorine compounds estimated from the highest PEC in the harbour was 0.041 in Yokohama Port and 0.054 in Rotterdam Port. Since both these values were less than 1, the environmental risk was not considered to be of concern. The PEC/PNEC of byproducts, bromoform, chloroform, dibromochloromethane, monobromoacetic acid, and dibromoacetic acid, was less than 0.1 and the environmental risk was not considered to be of concern. However, the highest PEC/PNEC of monochloramine was 41 in Yokohama Port and 38 in Rotterdam Port.

Table 5.2-30 PEC/PNECs of chroline compound and by-products in Yokohama port

Chemical name	In harbour PEC/PNEC		Surrounding PEC/PNEC	
	Max.	Average	Max.	Average
Chlorine compound (0.3 mg/L)	0.041	< 0.01	< 0.01	< 0.01
Bromoform	< 0.01	< 0.01	< 0.01	< 0.01
Chloroform	< 0.01	< 0.01	< 0.01	< 0.01
Dibromochloromethane	0.0102	< 0.01	< 0.01	< 0.01
Monobromo acetic acid	0.026	0.016	< 0.01	< 0.01
Dibromo acetic acid	0.055	0.034	< 0.01	< 0.01
Tribromo acetic acid	—	—	—	—
Chloramine/ Bromamine	41	25	1.0	0.32

Table 5.2-31 PEC/PNECs of chroline compound and by-products in Rotterdam port

Chemical name	In harbour PEC/PNEC		Surrounding PEC/PNEC	
	Max.	Average	Max.	Average
Chlorine compound (0.3 mg/L)	0.054	0.013	< 0.01	< 0.01
Bromoform	< 0.01	< 0.01	< 0.01	< 0.01
Chloroform	< 0.01	< 0.01	< 0.01	< 0.01
Dibromochloromethane	0.011	< 0.01	< 0.01	< 0.01
Monobromo acetic acid	0.020	0.011	< 0.01	< 0.01
Dibromo acetic acid	0.043	0.024	< 0.01	< 0.01
Tribromo acetic acid	—	—	—	—
Chloramine/ Bromamine	38	21	1.5	0.76

(8) Results and Discussion

a) Risks of residual chlorine (chlorine compounds) emitted during the use of seawater electrolysis systems

The PEC/PNEC of chlorine compounds in the scenario where the concentration of residual chlorine emitted from seawater electrolysis systems was assumed to be 0.3 mg/L (the same as the injection concentration) was less than 1. In addition, considering that injected chlorine compounds immediately start to degrade in water, the environmental risk of chlorine compounds emitted from seawater electrolysis systems in this scenario was not considered to be of concern.

The amount of emission water released from seawater electrolysis systems in this scenario was correspondent to the emission rate of ballast water per day (100,000 m^3) used in the emission scenario (Emission Scenario Document: ESD) discussed by the Ballast Water Working Group (BWWG) of the IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) (Yokohama Port = 29,152 m^3/day, Rotterdam Port = 224,471m^3/day in this scenario). The PNEC used in this assessment was estimated from chronic toxicity study data and the effect on environmental organisms coming into direct contact with the emission water in the local area immediately after emission was not considered. Therefore, it is desirable to introduce not only a long-term assessment but also acute and local assessments.

However, the GESAMP BWWG proposed that acute and local effects of chlorine compounds should be assessed based on the assumption that compounds were diluted to a tenth of their emission concentration and established a temporary criteria concentration of residual chlorine ranging from 0.1 to 0.3 mg TRO/L as Cl2 for ballast water management systems. Therefore, if the injection concentration of chlorine was 0.3 mg/L, since chlorine compounds degrade rapidly and the GESAMP BWWP considered that emission water from vessels was diluted 10-fold after emission, the concentration will have decreased in most cases. Consequently, the environmental risk, even after including the local and acute effects of chlorine compounds, was not considered to be of concern.

b) Risks of byproducts to environmental organisms

In the assessment of the environmental risks of byproducts generated by reactions with chlorine compounds injected via the seawater electrolysis system, the PEC/PNEC of all substances (except chloramine) was found to be less than 1. Based on the above results, it can be seen that the environmental risks associated with the use of seawater electrolysis systems are mainly related to chloramine, or combined chlorine. The environmental risk of all other byproducts, except chloramine, was not considered to be a concern.

c) Analysis of uncertainty in risk assessment results

The factors affecting uncertainty in the results of this risk assessment and the tasks carried out in the assessment are shown below.

i) Concentration of residual chlorine and byproducts generated during the use of seawater electrolysis systems

In this study, no data were available on the emission concentrations of chlorine compounds during the use of seawater electrolysis systems and the injection concentration was therefore used as the emission concentration. However, chlorine compounds can be expected to rapidly degrade within several seconds to tens of seconds after injection. Consequently, the actual emission concentration is probably lower than the injection rate.

Furthermore, the concentrations of chlorine compounds in the ballast water management system which was used for the identification of byproducts and the estimation of byproduct concentrations were several orders of magnitude higher than the emission concentrations found during actual use of seawater electrolysis systems. Therefore, the PEC of these byproducts could be overestimated. In addition, the actual retention time after injecting chlorine compounds into seawater electrolysis systems is shorter than that used in the ballast water management system. Consequently, the concentrations of trihalomethane, etc. are expected to be much lower again.

However, since full data were not available for generation and degradation rates, the environmental fate and the form of chloramine/bromoamine (the only substance with PEC/PNEC>1) existing in the environment, it was difficult to determine the risk of chloramine/bromoamine in this assessment.

ii) Emission amounts from seawater electrolysis systems

In this study, the cooling water volume (emission amount) produced by the seawater electrolysis system was set at 84 m^3/h/vessel during loading, and only 21 m^3/h/vessel (one fourth of the regular volume) at other times. The ratio of the loading period to the unloading period was estimated from the gross tonnage of ocean-going vessels (by vessel type and mooring time). Consequently, based on the assumption that all vessels arriving in Yokohama Port use the seawater electrolysis system, the total release volume of cooling water through seawater electrolysis systems in Yokohama Port was estimated to be 29,152 m^3/day. Similarly, the volume in Rotterdam Port was estimated to be 224,471 m^3/day. In the current approval review of ballast water management systems, the emission volume of treated ballast water in a model port is defined as 100,000 m^3/day in the worst-case scenario.

The emission volume produced by the seawater electrolysis system in this study is considered to be almost equal to that of the ballast water management system in the worst-case scenario. Therefore, the emission volume produced by the seawater electrolysis system could be overestimated in this scenario. In the IMO criteria for emission water, the upper concentration of chlorine at emission is defined as 5 mg/L because the volume of wastewater (after human waste disposal) is small. However, as mentioned above, the upper concentration of chlorine in the ballast water was set at 0.3 mg/L and even if the emission volume of seawater produced by the electrolysis system is almost equal to that of the ballast water, the risk to environmental organisms posed by chlorine compounds emitted from seawater electrolysis systems is not considered to be of concern.

d) Risks of chloramine to environmental organisms

In this study, chloramine (monochloamine), one of the halogenated amine byproducts, was selected for further study and the risk posed by chloramine was assessed. Consequently, the PEC of chloramine at the highest concentration in the harbour was estimated to be 0.448 mg/L and the PEC/PNEC was estimated to be 41 in Yokohama Port.

Although bivalve hard clam larvae were not used for the PNEC estimation in this study because they are not a standard species for risk assessment, the 48-hr LC_{50} of chloramine for hard clam larvae was 0.001 mg/L. This value is correspondent to approximately a tenth of the toxicity for water flea, which was used for the PNEC estimation in this study. Consequently, it can be seen that there are environmental organisms available which have a higher sensitivity to chloramine than the standard test species normally used for risk assessment. Since the PEC of chloramine in Yokohama/Rotterdam Port in this scenario is correspondent to approximately half the LC_{50} in bivalves, local effects on environmental organisms near emission sources (vessels) cannot be ruled out. It has been shown that bromoamines can be generated in seawater more easily than chloramines, although bromoamine was not selected for study in this assessment because sufficient data were not available (Taylor, C.J.L., 2006). Therefore, it would be helpful for environmental risk assessment purposes to collect data on the toxicity and generation/degradation mechanisms for the entire range of halogenated amines, including bromoamines. However, since both chloramine and bromoamine are unstable in water and difficult to measure, it is probably difficult to obtain reliable data on their toxicity and degradability.

5.3 Risk estimation for novel techniques, including improvements

Risks posed by the current techniques are assessed in Section 5.2. It is expected that antifouling performance will be improved and that more advanced removal techniques will be developed. Improved antifouling performance and more frequent removal could increase the risks posed to environmental organisms. For example, compounds that are hazardous to organisms and/or highly-concentrated chemicals could be used to prevent biofouling. Therefore, prior to the introduction of improved antifouling performance and removal techniques, it is important to assess the relative risk of these improved techniques in comparison with the standard techniques normally employed at present.

In Section 5.3, the environmental risks of the improved treatment that is expected to be utilized in the future are discussed: [1] increased environmental risks from compounds involved in IWC implementation if the IWC frequency is increased to twice/year and IWC is used on all vessels, and [2] improved performance of the seawater electrolysis system and changes in risks due to the expanded range of use. The resultant increase/decrease in risks caused by the improved treatment in comparison with the current base treatment was also assessed.

5.3.1 Risks of compounds leaching from antifouling paints

Improved (future) antifouling paints are expected to possess increased antifouling performance in comparison with the current treatment and the type, toxicity, leaching amount and rate, etc. of active substances in these antifouling paints could also be changed by the adoption of a comprehensive control system. However, it is difficult to predict the properties and toxicity of newly developed or improved AFCS and antifouling paints based on the information available at present. Therefore, the environmental risk of improved (future) antifouling paints was not assessed.

5.3.2 Risks of IWC

(1) Exposure scenarios

The scenario for the use of improved (future) antifouling paints differs from the current exposure scenario described in Section 5.2.5 (3) in the following ways:

- The frequency of IWC implementation: In future, IWC may be implemented to prevent the transfer of biofouling alien species. Consequently, the frequency of IWC implementation will be higher than at present. In future, IWC implementation is expected to be carried out once/year. However, the worst case is assumed to be twice/year in ocean-going vessels because IWC will be immediately implemented after confirming the presence of any macro biofouling.
- The site of IWC implementation (port): IWC is currently implemented in only a limited number of ports. However, it is assumed that IWC will, in the future, be implemented in almost all ports that ocean-going vessels enter. Consequently, the frequency of IWC implementation in Yokohama Port (currently 0.398 vessels/day) is estimated to fall to 0.318 vessels/day in future.
- The coverage of biofouling organisms and the thickness of painted pieces scraped off by IWC: The coverage of biofouling in future is expected to be less extensive than the current coverage because IWC will be implemented at shorter intervals than at present. Therefore, the thickness of painted pieces scraped off by IWC is expected to be very thin because soft brushes will be used on almost all components (99%). On the other hand, while biofouling by organisms with fast growth rates still cannot

be ruled out, it is assumed that relatively severe biofouling will be observed only on a minimal area (1%) of the outer hull skin and thicker (500 μm) painted pieces will be scraped off there.

- The percentage of compounds remaining in the painted pieces scraped off by IWC: The percentage of compounds remaining is not expected to decrease in the painted surface (remaining percentage = 100%) in future because the interval of IWC implementation will be shorter than at present.

The effectiveness of the collection of IWC-removed materials in reducing the amount of active substances released in the future is not included in this assessment. The future exposure scenario used in this assessment assumed that the reduction in the concentrations of compounds in the painted surface during IWC implementation will be zero. However, in actual practice, the concentrations are estimated to decrease in accordance with the leaching rate and hydrolysis occurring in the coated surface. Therefore, the actual amounts of active substances released as a result of any future IWC are expected to be smaller than the amounts estimated in the worst-case scenario used in this assessment.

Table 5.3-1 Emission scenario and its parameters of IWC under future improvement

Parameter	Bio-coverage		Rationale
	Slight	Heavy	
Hull bottom area per vessel (m^2/vessel)	4,602		Calculated by the Froude equation
Ratio of the vertical part in the hull area (%)	38		According to the survey, bottom/ vertical part in the hull area is ca 62/38.
Ratio of IWC in the vertical part of the hull area (%)	70		Same as current IWC
Ratio of IWC area in the hull area (%)	26.6		Same as current IWC
IWC application area per vessel (m^2/vessel)	1,224		Obtained from the hull bottom area and IWC application area
Frequency of IWC (times/year/ship)	2		Under future scenario, IWC is applied twice a year for every vessel regardless of degree of biofouling.
Frequency of IWC applied vessels in Yokohama-port (times-IWC/ ship-Yokohama)	0.1		Compared to the current scenario, much many ports can conduct IWC and one tenth of vessels arrive in Yokohama is carried out IWC (1/5 of the current IWC).
Daily number of IWC in Yokohama-port (times-IWC/day/Yokohama)	0.318		Obtained from global number of ocean-going vessels and cargo volumes in Yokohama IWC is done every two year.
Daily IWC total area (m^2/day/Yokohama)	389		Obtained from IWC area per vessel and daily number of IWC.
Thickness of removed paint chips (μm)	5	500	Assumed that biofouling is slight in 99% of area and used soft brush (5 μm) but heavy in 1% and used hard brush (500 μm) for IWC.
Ratio of each paint chips (%)	99	1	
Density of removed paint chip (g/m^3)	1.69		According to AIST Initial Risk Assessment (pyrithione copper)
Contents in AFCS (wt-%) (pyrithione copper)	3.66		According to AIST Initial Risk Assessment (pyrithione copper)
Contents in AFCS (wt-%) (other than pyrithione copper)	5		Worst case is used since no information is available.
Remaining part of active substance in paint chips when IWC is done (%)	100		Assumed that no loss of active substance in removed paint chips has been occurred when IWC is done.
Non volatile part of paints (%)	50		Assumed that content of volatile solvents in original paint is 50%.

Table 5.3-2 Emission rate of active substance due to IWC in future use

	Emission rate (g/day)		Total emission rate (g/day)	Rationale
	Coverage of biofouling			
	Slight	Heavy		
Yokohama-port, CuPt	238	241	479	Daily emission rate of active substance due to IWC in Yokohama port
Yokohama-port, other than CuPt	326	329	655	
Rotterdam port, CuPt	1,835	1,854	3,689	Daily emission rate of active substance due to IWC in Rotterdam port
Rotterdam port, other than CuPt	2,507	2,533	5,040	

CuPt: Pyrithione copper

(2) Environmental risks of future (improved) IWC

The MAM-PEC model used in this assessment estimates the PEC in proportion to the emission rate (g/day) used as input data if the environmental conditions and the data on compound properties are equivalent. Consequently, the ratio of the emission rate of the current treatment in Table 5.2.11 to the emission rate of the improved treatment can be considered to represent the difference in environmental risk. Therefore, the environmental risk of IWC in future (improved) well-controlled conditions is estimated to be appropriately 1/3.8 that of the current IWC process.

To be specific, the use of soft brushes and the dispersion/increase of IWC-available ports could decrease environmental risks and reduce the chemical risks posed by antifouling paints to acceptable levels, even if the IWC area and frequency of use increase.

(3) Estimation of continuous leaching time for compounds leaching from painted pieces scraped off by IWC

Compounds in painted pieces released into the surrounding sea area due to IWC are considered to be continuously leaching out for a certain amount of time, as expressed by the leaching rate. Painted pieces scraped off hull surfaces by IWC are expected to settle in sediments after a certain amount of time, although the actual settling time depends on the size and density of the pieces and the prevailing ocean currents. To estimate which environmental compartment (water, sediment, etc.) would be a target for compound emission due to IWC implementation, the continuous leaching time was estimated using the leaching rate of the compounds contained in the antifouling paints used.

To limit the amount of uncertainty in the calculations, the continuous leaching time was estimated using an exposure scenario for future IWC that assumed no change in the compounds included in the painted pieces scraped off by IWC. In this case, a painted piece scraped off by IWC was simply assumed to have double the surface area of the hull bottom surface. Consequently, the total surface area of painted pieces scraped off by IWC per day was estimated to be double that of the AIWC-total given in Table 5.3-1. Based on the above calculation, the total surface area of painted pieces scraped off by IWC was estimated to be 389 × 2 = 778 m^2/day in Yokohama Port and 5,990 m^2/day in Rotterdam Port. It was assumed that the leaching rate of compounds in painted pieces scraped off by IWC was equal to the leaching rate of compounds in the hull surface and that the leaching rate does not change. The continuous leaching time in the above scenario is estimated below.

Table 5.3-3 Estimated leaching time from paint chips after removed from ship hull by IWC

	Leaching rate ($\mu g/cm^2/day$)	Leaching time (day)	
		Yokohama	Rotterdam
Copper (I) oxide: Cu_2O	40	0.63	0.63
Zinc pyrithione	4.57	5.5	5.5
Copper pyrithione	2.88	5.4	5.4
Total copper (dissolved form)	35.5*[1]	0.7	0.7
Total zinc (dissolved form)	0.94*[2]	27	27
TBT	1.9	13	13

*1: Leaching rate of total copper is a sum of copper oxide and copper pyrithione which are converted to copper using ratio of molecular weights.

*2: Leaching rate of total zinc is obtained from zinc pyrithione which is converted to zinc using ratio of molecular weights.

The continuous leaching time described above depends solely on the leaching rate and the chemical content in the painted pieces. Therefore, the time spent in Yokohama Port can be considered equal to that in Rotterdam Port. In this scenario, the leaching time of zinc (with the lowest leaching rate) was 27 days whereas that of copper (I) oxide (with the highest leaching rate) was 0.63 days (15 hours or more). All active substances were estimated to be completely leached from painted pieces after 0.63–27 days.

Considering these results, compounds leaching from painted species scraped off by IWC were considered to be mainly distributed in the water. Therefore, the risks posed by these compounds to benthic and terrestrial organisms, which were not included as subjects of this assessment, were not considered significant. The increase in environmental risk posed by IWC is therefore considered to be limited, taking into account the estimated continuous leaching time of the compounds involved.

(4) Concentration and behavior in sediment of painted pieces scraped off by IWC

In this assessment, since most of compounds leaching from antifouling paints and released by IWC were assumed to be found in the water, it was the risks posed to aquatic organisms that were assessed. On the other hand, the MAM-PEC model used in this assessment can estimate concentrations in both water and sediment. The MAM-PEC model estimates the concentration of compounds in sediment based on the assumption that compounds neither move nor degrade after being distributed in the sediment. Consequently, the PEC of copper (I) oxide leaching out from antifouling paint in Yokohama Port was estimated to be 2,390 ng/L in water while the concentration in sediment was estimated to be 71.8 μg/g-dry soil. Therefore, a simple comparison per volume shows that the concentration in sediment was approximately 30,000 times higher than that in water. In actual marine environments, compounds in sediment can leach or move into water, degrade or change their chemical form. Therefore, the actual concentration in sediment is estimated to be lower than that described above. For a full environmental risk assessment, it may be necessary to improve the MAM-PEC model and develop a multi-media model incorporating concentrations encountered in actual environments.

5.3.3 Risks of applying the seawater electrolysis system to open system sites such as sea chests

Risks posed to environmental organisms from compounds produced by the seawater electrolysis system were discussed in Section 5.2.5. The risk posed by the use of an improved technique in open system sites such as the sea chest was assessed as shown in the following paragraphs.

(1) Establishment of the exposure scenario and estimation of the PEC of chlorine compounds

Using similar procedures to those described for AFCS use and IWC processing, above, a model port (Yokohama and Rotterdam Port) was established and the operating conditions for the seawater electrolysis system and the exposure scenario for chlorine compounds were designed using a simulation model (MAM-PEC model ver. 2.5). The concentration of residual chlorine on release (as required for PEC estimation purposes) was determined to be 1 and 3 mg/L, since it was expected that a higher chlorine concentration would be needed for the sea chest than for the inner piping of the cooling water system.

No quantitative data for the emission rate of an improved seawater electrolysis system were available, however, so the possibility that compounds could be drawn into the cooling water near the seawater inlet could not be ruled out. Therefore, in this scenario, the values used were equivalent to the volumes described in Section 5.2.5 for the standard technique currently in use, i.e., 29,152 m^3/day for Yokohama Port and 224,471 m^3/day for Rotterdam Port, as the worst case.

The assessment of byproducts has been omitted in this paragraph because the assessment in Section 5.2.5 used the highest concentration detected in the ballast water management system and the conditions, including the flow volume, were equivalent to those used with the current standard technique.

Emission rates for chlorine compounds were estimated from the chlorine concentrations used in an improved technique scenario, and the amounts of water released and the PEC were estimated using the MAM-PEC model. The estimated emission rates of chlorine compounds and byproducts are shown below.

Table 5.3-4 Emission rates of chlorine compounds in Yokohama and Rotterdam ports (g/day)

Emission scenario	Yokohama	Rotterdam
Chlorine compound: 1 mg/L	29,152	224,471
Chlorine compound: 3 mg/L	87,456	673,413

Environmental parameters in Yokohama/Rotterdam Port used to estimate the PEC with the MAM-PEC model and the physicochemical properties and environmental fate data were correspondent to those described in Section 5.2.5.

(2) Estimation results for PEC

The PECs of chlorine compounds in Yokohama/Rotterdam Port (the highest and mean concentrations in the water) that were estimated by the MAM-PEC model using the abovementioned scenario are shown below. In this study, the background concentration was not considered.

Table 5.3-5 PECs of chlorine compounds in Yokohama port

Emission scenario	In harbour PEC (μg/L)		Surrounding PEC (μg/L)	
	Max.	Average	Max.	Average
Chlorine compound: 1 mg/L	0.11	0.0261	1.20E-04	3.64E-05
Chlorine compound: 3 mg/L	0.329	0.0783	3.59E-04	1.09E-04

Table 5.3-6 PECs of chlorine compounds in Rotterdam port

Emission scenario	In harbour PEC (μg/L)		Surrounding PEC (μg/L)	
	Max.	Average	Max.	Average
Chlorine compound: 1 mg/L	0.143	0.0333	2.23E-04	1.12E-04
Chlorine compound: 3 mg/L	0.429	0.1	6.69E-04	3.36E-04

(3) Estimation of PNEC

The PNEC was estimated using the toxicity data for chlorine compounds collected and compiled in Section 5.2.5.

Table 5.3-7 PNEC of chlorine compound

Chemical name	Species	Endpoint	NOEC (μg/L)	Assessment factor	PNEC (μg/L)
Chlorine compound (NaClO)	Tidewater silverside (*Menidia peninsulae*)	28-d NOEC	40	50	0.8

(4) Results of risk assessment (PEC/PNEC)

The assessment results for the risks posed by chlorine compounds in the use of an improved seawater electrolysis system are shown below.

The PEC/PNEC with 1 or 3 mg/L of chlorine compounds (residual chlorine) was less than 1 in all conditions.

Table 5.3-8 PEC/PNECs of chlorine compounds in Yokohama port

Emission scenario	In harbour PEC/PNEC		Surrounding PEC/PNEC	
	Max.	Average	Max.	Average
Chlorine compound: 1 mg/L	0.138	0.0326	< 0.01	< 0.01
Chlorine compound:: 3 mg/L	0.411	0.0979	< 0.01	< 0.01

Table 5.3-9 PEC/PNECs of chlorine compounds in Rotterdam port

Emission scenario	In harbour PEC/PNEC		Surrounding PEC/PNEC	
	Max.	Average	Max.	Average
Chlorine compound: 1 mg/L	0.179	0.0416	< 0.01	< 0.01
Chlorine compound: 3 mg/L	0.536	0.125	< 0.01	< 0.01

(5) Results and Discussion

The assessment of environmental risk for an improved seawater electrolysis system showed that the PEC/PNEC of residual chlorine was less than 1 even though the residual chlorine concentration was assumed to be 3 mg/L on release. Therefore, the environmental risk of chlorine compounds emitted from a seawater electrolysis system when used for the sea chest was not considered to be of concern.

The amount of emission water produced by the seawater electrolysis system in this scenario is the value used in the worst-case example because no other quantitative data were available. Consequently, the PEC could have been overestimated in a similar way to the assessment results for the risks posed by the current seawater electrolysis system used in section 5.2.5. The risk posed by chlorine compounds from both current and improved seawater electrolysis systems to environmental organisms was not considered to be of concern, even in the worst-case scenario.

The criteria used for the emission of water from the seawater electrolysis system used for antifouling have not been discussed (even by the IMO) and injection and emission concentrations are not monitored and no accurate concentration data for residual chlorine in the current system are available. Therefore, to use this system as an antifouling technique for the sea chest, etc., it is necessary to determine the lowest possible chlorine concentration that can provide an assured antifouling effect and the highest chlorine concentration for which there is no chemical environmental risk, and to then control the balance between them. Especially in the seawater electrolysis system, it is difficult to control the concentration of residual chlorine due to changes in flow volume and the salt concentration in seawater, and sometimes the concentration falls outside the setting range. Therefore, it is desirable to continuously monitor the concentrations of chlorine compounds and develop a safety feature such as an automatic stopping system, etc.

Furthermore, continuous use at a high concentration can cause chemical corrosion in hulls as well as environmental risks. If the concentration of chlorine is appropriately controlled, concentrations at the outlet may not always be equal and the highest permitted concentration (e.g. 3 mg/L) at specified point(s) can then be established. One approach is to reduce the total injection amount needed by switching injection concentrations along the time-line and this has already been tried as an antifouling technique for onshore facilities that use seawater.

5.4 Summary of chemical environmental risk assessment

To appropriately control the environmental risks posed by chemical compounds produced by various techniques used to prevent/remove biofouling on ship hulls, it is important to quantitatively assess the risks on the basis of reliable chemical data and apply results to actual operations. A full environmental risk assessment requires additional data to optimize the exposure scenario, including the effectiveness of a recovery net in reducing the emission rate in IWC, information on the content of compounds in painted pieces scraped off by IWC, and an accurate determination of the leaching rate. Basing the environmental risk assessment on PEC/PNEC values always requires the estimation (determination) of specific concentrations for each compound. However, compounds leaching from antifouling paints are expected to exist in a variety of extremely complex forms in actual marine environments. In particular, the active substances found in self-polishing antifouling paints, which often form metal complexes, can remain in the environment for a long time because metal ions may react with other natural chelates, even though the complexes formed eventually degrade in the environment. Similar complexity can also occur in the generation of chloramines due to the use of seawater electrolysis systems. It can be difficult to accurately assess (determine) the existing forms and concentrations of compounds in natural seawater, even when using current analysis techniques and simulation models for chemical reactions. It should be noted that environmental organisms are exposed to various compounds in mixed conditions and that two or more compounds are often used simultaneously for antifouling purposes. Therefore, to accurately assess the environmental risks of compounds used for antifouling and removal, it is also necessary to assess these combined toxicity effects.

To improve the reliability of the assessment process for environmental risks regarding the use of antifouling treatments, assessments could be carried out using the whole effluent toxicity (WET) technique, which does not require estimation (determination) of each individual compound concentration. In assessment with WET, ecotoxicity studies involving seawater containing two or more compounds leaching out from an antifouling paint already applied can be successfully conducted and the toxicity of compounds in various forms in the seawater can be successfully assessed. On the other hand, assessments using WET have confirmed that the toxicity of metal compounds depends on the type and concentration of the dissolved inorganic ions and organics present. Therefore, all studies should be conducted using natural seawater rather than artificial seawater.

6. Risk of species transferring

6.0.1 Management carried out in order to reduce the risks of transferring biofouling organisms is expected to be controlled by internationally binding regulations. However, since there is no report in place yet to assess the risk of transferring biofouling organisms it will be necessary to hold further discussions on regulations regarding species transfer in order to assess the risks and establish the appropriate standards, based on scientific evidence.

6.0.2 It is difficult to predict whether or not a species is likely to transfer and settle in the sea area of other countries, based on marine biology aspects alone. Therefore, the risk of invasion by organisms cannot be directly assessed. Marine biology cannot provide a suitable analysis system to describe the risk in terms of a relationship between the quantitative amount transferred (the dose) and the results (the response), as used in chemical environmental risk assessment. This chapter proposes a new approach to estimate and assess the risk of organism transfer when using the best prevention and removal methods currently available. As part of this risk estimation process, the effects of those techniques currently considered most useful for the prevention and removal of biofouling were evaluated. In particular, the change in relative dose (including the amount of biofouling organisms transferred and the burden that these attached organisms impose on the new environment) was assessed in order to determine the risk. The change (or percentage change) in the amount of organisms transferred or the burden imposed was considered to correspond to the dose of the dose-response relationship used in chemical environmental risk assessment and the risk was assessed in comparison with the amount of organisms being transferred (the dose).

6.0.3 When assessing the risk of transferring biofouling organisms, the biological parameters that can be used as the dose are the number of biofouling organisms and the number of eggs spawned in the port area by organisms that reach sexual maturity after attachment (i.e., 2 possible invasion routes). However, the number of biofouling organisms per unit area is unlikely to be of use as a biological parameter because the probability of the organisms surviving transfer by ship cannot be estimated. In contrast, since the egg production derived from organisms that have reached sexual maturity after attachment can be determined for each individual species and ship, this is an appropriate biological parameter for use as the dose when assessing the risk of species transfer. Based on the above considerations, the risk of species transfer was assessed in terms of relative changes in the egg production derived from organisms that reached sexual maturity after attachment and this was then used as the dose in each of the 13 scenarios included in this survey. This assessment model has been newly developed and is a world first.

6.0.4 Most anti-fouling coating systems (AFCS) involving antifouling paints for the outer hull skin of ships are specified to have a 3-year antifouling effect by Japanese antifouling paint manufacturers. The accumulated egg production over the period of 3 years after a ship is processed with antifouling paint with a 3-year antifouling effect was considered the standard case and compared with other test cases with different parameters. Comparing 3-year accumulated egg production on a ship that had been processed with improved antifouling paint having a 5-year antifouling effect, the dose after use of the improved antifouling paint was found to have decreased to approximately 20% of the value obtained in the standard case, confirming that the improved antifouling paint had significantly reduced the risk of transferring any biofouling organisms.

6.0.5 Current antifouling paint performance, overall, is generally less effective than specified. Therefore, the additional risk associated with the use of in-water cleaning (IWC) to remove attached materials was not estimated to be high. Consequently, it is not considered necessary to ban IWC immediately. In addition, the collection of removed material is effective, even when carried out using a net with a relatively large mesh size. The risk of organism transfer would probably be reduced even more by collecting removed material using a net with a smaller mesh. The collection of the material removed by IWC will significantly reduce the risk of organism transfer at the global level. Therefore, the implementation of IWC in conjunction with a suitable device for collecting all material removed can be considered an effective component of a comprehensive antifouling control system.

6.0.6 In conclusion, after comparing the various techniques assessed as part of this survey in terms of their effectiveness in decreasing egg production by biofouling organisms to the current (standard) level, or less, and reducing the associated risk of organism transfer, the use of an antifouling paint with advanced antifouling performance was considered to be the most effective measure available. However, considering the current conditions associated with biofouling on ship hulls, it would be difficult to maintain the hull surface in an acceptable condition without macro biofouling solely through the use of an advanced antifouling paint. Therefore, IWC is an effective supplementary measure and the appropriate collection of materials removed by IWC (removed organisms) is also a useful means of reducing the risk of organism transfer. With regard to sea chests (for which no effective measures have yet been established), one possibility is that the sea chest (especially around the inlet) could be treated with the type of seawater electrolysis system that has previously only been used for the seawater cooling system in ships. The use of IWC could be expected to decrease egg production even further. Therefore, promising measures are being considered for IWC and an advanced system incorporating appropriate devices for collecting all removed materials (removed organisms).

6.1 Assessment method for the risk of species transfer

Even if a certain species is transferred from its original habitat by human actions and confirmed to still be alive on arrival in a distant sea area, it is currently difficult to confirm whether or not that organism will be able to successfully settle there. Therefore, in this chapter, two concepts and terms are introduced regarding the "risk of invasion" (see Table 7.1-1) and the "risk of aquatic species transferring", (see Table 7.1-1).

6.1.1 Risk assessment methodology

In the assessment of chemical environmental risks, as described in Chapter 5.1 Assessment methods for chemical environmental risks, a dose- response relationship can be established between the exposure concentrations of chemical compounds and their effects on organisms (Figure 6.1-1). For example, as shown on the graph below, while the concentration gradually increases from zero, organisms can still tolerate the effect up to a certain concentration. However, the severity of the effect then increases rapidly above that concentration. If the concentration continues to increase, the effect eventually becomes constant and is no longer dependent on the specific concentration. The effect can be assessed by various indicators in terms of endpoints such as mortality, increase in individual wet weight and reproduction, and these endpoints can be expressed as reproducible logarithmic curves. A curve representing such a relationship is called a dose-response curve.

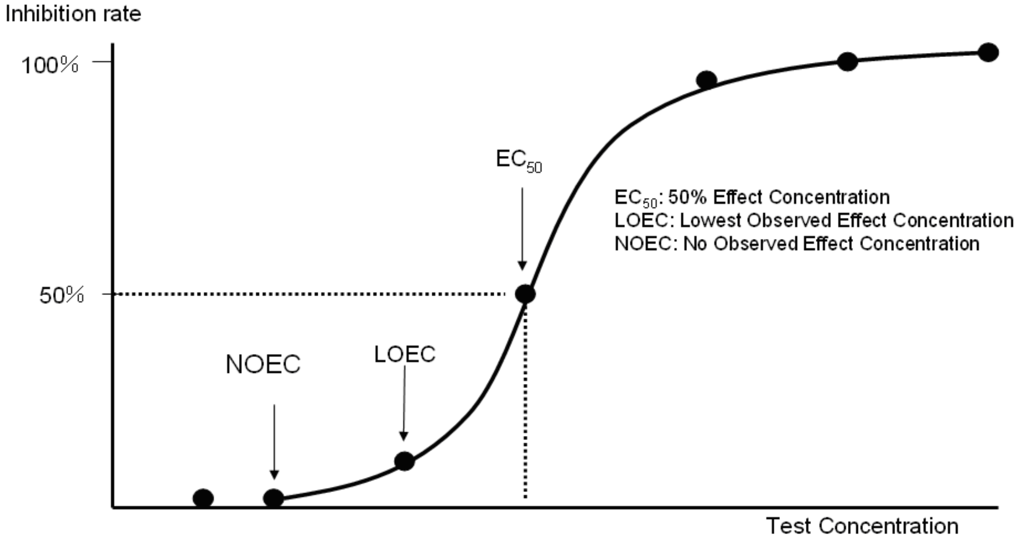


Figure 6.1-1 Dose-response curve of eco-toxicity data

Based on the assumption that such a relationship can be established, a predicted non-effect concentration (PNEC) is then estimated from toxicity study results such as the 50% lethal concentration (LC$_{50}$), 50% effective concentration (EC$_{50}$), lowest observed effect concentration (LOEC) and the no observed effect concentration (NOEC) by using appropriate assessment factors. Finally, the PNEC (concentration) is used to estimate the concentration that has almost no effect on most environmental species, based on toxicity study results obtained using model animals. Furthermore, based on the environmental conditions of the target sea area and environmental fate data, including the physicochemical properties and degradability of the chemical compounds in question and the amounts of chemical compounds released, a predicted environmental concentration (PEN) can be estimated using dispersion, partition-equilibrium and chemical reaction simulation models. A common evaluation method used worldwide for chemical environmental risks makes use of the ratio of PEC to PNEC (PEC/PNEC).

In contrast with the assessment of chemical environmental risks, evaluation methods needed to assess biological risks have not yet been fully developed.

One issue concerning the transfer of marine species is that a new species settling in a new area can cause various changes in biota such as the expulsion of native species and decreased biodiversity. In particular, social problems can arise when such changes have a significant effect on the environment and/or human health. The issue of ballast water, for example, which is associated with marine species transferred by means of human activities and with biofouling organisms, was discussed with reference to several tens of damage cases at the meeting of the International Maritime Organization (IMO) held in 2004 and, as a result, the Ballast Water Management Convention was adopted. However, no quantitative risk assessments were conducted for species transfer when the convention and guidelines were first developed.

There are no international regulations equivalent to those of the Ballast Water Management Convention in place yet regarding the risks of biofouling organism transfer. Although no reports have yet been produced on the human health hazard posed by biofouling organisms, economic effects and effects on the ecosystem have already been confirmed. If the guidelines currently being developed are adopted by the IMO, the issues concerning the invasion of alien species by means of the biofouling of ships will become internationally recognized and information on many cases of damage will be more readily available. Consequently, it is expected that risk management involving the transfer of biofouling organisms will eventually be controlled by internationally binding regulations, similar to those adopted for ballast water management.

Invasive risks posed by alien species are recognized in terms of the process of transfer, settlement and damage. Settlement, in this process, means that the transferred species successfully attain the ability to reproduce continuously in the new habitat. Organisms that are merely transferred (and do not settle) are not necessarily recognized as alien species in the environment and may not pose a problem. This means that the introduction of only a very small number of alien organisms is not necessarily capable of causing significant environmental damage.

Therefore, a threshold for the settlement of alien species can be established and the invasive risks of alien species estimated on the basis of this threshold. On the other hand, an alternative approach could use the level that causes damage to human health and industry as a threshold of risk. The level of risk posed by an alien species whose settlement causes no damage corresponds to the predicted non-effect concentration (PNEC) in the chemical environmental risk assessment process. The endpoints used determine whether damage is considered in terms of the settlement of alien species in an ecosystem or as a human health hazard.

The response caused by the settlement of an alien species cannot currently be determined in a similar way to that used in chemical environmental risk assessment. Consequently, a dose-response relationship has not yet been established on the basis of scientific evidence. As a result, several countries already damaged by alien species have adopted various measures to prevent alien organisms from invading their ecosystems, based on the precautionary principle (taking measures to address unknown risks in advance). However, as shown by frequent discussions on the relationship between carbon dioxide concentration and temperature rise, individual case reports of health hazards and/or industrial damage, alone, are insufficient to meet the considerable requirements for prevention by countries all around the world. Therefore, it is necessary to establish a dose-response relationship between alien organisms and the resultant damage. However, it is very difficult to determine how best to select a suitable response to a given dose. The responses displayed by different organisms to a given dose vary and depend on physiological, biotic and abiotic conditions. Quantitative assessment of the dose and proposals for a comprehensive management technique based on these assessment results can provide a suitable approach for establishing a dose-response relationship and effective measures to counter alien species.

Therefore, in this survey, the changes in relative dose (including the amount of biofouling organisms and the burden that these organisms impose on a new environment) were investigated in order to assess the risk of transferring biofouling organisms. The change or percentage change in the amount of organisms transferred or the burden imposed is considered to correspond to the dose of the dose-response relationship used in chemical environmental risk assessment.

When assessing the risk of transferring biofouling organisms, biological parameters used as the dose include 2 separate indicators - the number of biofouling organisms and the number of eggs spawned by sexually mature organisms (hereinafter referred to as egg production). The number of biofouling organisms is unlikely to be of use as a biological parameter because the probability of the organisms surviving transfer by ship cannot be estimated. Furthermore, if the number of biofouling organisms is large, but most of them are immature, the risk is estimated to be low because of the lack of spawning.

In contrast, sexually mature organisms can undergo repeated spawning during egg-laying periods in biofouling conditions and then move to the sea bed due to removal by IWC. Since egg production can be determined for each individual species and ship, it is appropriate to use this biological parameter as the dose if the country/area where an organism was attached to a ship can be identified. In addition, the adoption of egg production as the dose also facilitates the assessment of settlement by the next generation because some of the eggs spawned will also grow and reproduce.

Therefore, this survey adopted egg production as a dose parameter to assess the risk of transferring biofouling organisms and compared changes in egg production in different scenarios to assess the effectiveness of each technique used to reduce the risk.

As part of the risk assessment process for the transfer of biofouling organisms in this chapter, spawning carried out during round-trip shipping between the northern and southern hemispheres was selected as a test model and egg production from organisms reaching sexual maturity after attachment was estimated. An assessment was then carried out of the relative effectiveness of different antifouling and removal techniques used on biofouling organisms. (However, this estimation process is currently only a preliminary calculation and not an internationally recognized standard). In this chapter, the risk posed by the egg production of clams was expressed as a dose (or a change in dose).

Some animals that cannot attach to a ship hull by themselves (mobile species including shrimps, crabs, Gammaridea, Caprellidea and conchs) may also be transferred as these organisms can voluntarily abandon a ship after making use of it as a transient habitat. Since it can, therefore, be difficult to determine the number of biofouling organisms, these species were not adopted as part of the prediction model.

6.1.2 Outline of the model used to estimate the risk of species transfer

(1) Basic conditions of the model used to estimate the risk of species transfer

Several basic conditions, including the shipping schedule and associated factors, the species of organism attached to the ship, and relevant indicators such as growth and spawning (see Table 6.1-1) were established before using the model to estimate the risk of species transfer. In this survey, the number of organisms attached to the hull skin was expressed in terms of pieces/10,000 mm^2.

Table 6.1-1 Basic conditions of the model

Item	Factor	Setting
Ship	Shipping route	A round trip between country A in the northern hemisphere and country B in the southern hemisphere
	Shipping schedule	20-day round trip, 2.5-day cargo handling × 2, totaling 25 days/round trip
	Interval between docking	3 years
	Paint	Self-polishing antifouling paint
	Frequency of round trips	48 trips/year 48 ships that leave dock and depart on the 1st or 15th of each month from countries A or B.
Biofouling organism	Type	Barnacle, clam Different species are selected in countries A and B, respectively.
	Reproductive system	Sexual reproduction by in-water spawning
	Period of attachment	Northern hemisphere: 2 months from July to August; Southern hemisphere: 2 months from January to February
	Size of larvae at time of attachment	Radius of attachment part: 0.15 mm
	Number of larvae attached per day	4/10,000 mm^2/day (during the above laying period only)
	Growth rate (radius of attachment part)	Radius up to 5 mm: 0.025 mm/day Radius more than 5 mm: 0.0005 mm/day
	Maturation period	200 days
	Size during the sexual maturation period (radius of attachment part)	5 mm
	Size one year after attachment (radius of attachment part)	5.08 mm
	Laying period [*1, *2] (same as the attachment period)	Northern hemisphere: 2 months from July to August; Southern hemisphere: 2 months from January to February [*2]
	Egg production	5.58×10^5/individual
	Life span	5 years

*1: The laying period of most biofouling organisms is generally around summer. In the assessment carried out in this survey using models, the objective was to compare the performance of different techniques using egg production as an indicator. Therefore, since it is important to detect any differences in performance as simply as possible, the model used was based on the assumption that the laying period was 2 months in summer (winter in the southern hemisphere).

*2: If biofouling organisms live only in the northern hemisphere, they do not spawn within one year of their birth. However, organisms attached in the northern hemisphere may continue to grow (assuming a 5 mm radius) and develop mature ovaries due to factors such as the increased water temperature when they are transferred to the southern hemisphere in a season when similar species spawn there also. Therefore, the worst-case scenario assumed that organisms can spawn earlier than normal, within their first year, due to transfer by humans.

(2) Basic model formulae

The behavior of organisms in the early development period is an important component of the growth model for marine organisms, regardless of species. The antifouling effect of self-polishing antifouling paint consists of [1] preventing larvae attaching to a painted surface and [2] removing attached larvae with a still underdeveloped byssus or cementum layer immediately after attachment by peeling off micro flakes (with larvae) from the surface at a constant flow rate. Therefore, the model consists of two core formulae expressing the effect of self-polishing antifouling paint in preventing biofouling by larvae and the effect of self-polishing antifouling paint in peeling off the surface, as well as a combination of these formulae expressing the number of biofouling organisms, a formula expressing the process of sexual maturation of biofouling organisms, and a formula expressing the egg production by sexually mature organisms.

These formulae are all time functions. Consequently, the number of biofouling organisms that can be estimated from these formulae depends on the amount of time spent in port during the laying period and the time when the ship leaves the dock (because the antifouling effect on larvae depends on the time span involved).

a) Determination of the antifouling effect of self-polishing antifouling paint on larvae

In the model, the antifouling effect on larvae is expressed by the change in the number of organisms attached per day. The antifouling effect during an arbitrary period of time depends on the length of the attachment-free duration (based on the antifouling painted attachment conditions and the number of organisms attached per day) and the amount of time elapsed since attachment.

The current self-polishing antifouling paint with a 3-year antifouling effect is expected to leach antifouling active substance at high concentrations soon after processing. Therefore, larvae are not considered able to attach to a ship body for 30 days after leaving dock. Subsequent conditions can be established as follows: the leaching rate of antifouling ingredients decreases constantly and micro biofouling starts to form, with the antifouling effect gradually decreasing and disappearing altogether within 3 years of leaving dock (1,095 days).

Larva attachment during the period ($30 \leq d \leq 1{,}095$ days) in which the antifouling paint effect is gradually decreasing is expressed by the following formula:

$$n=0 \quad (0 \leq d \leq 30) \cdots\cdots\cdots\cdots\cdots\cdots \quad (6.1)$$

$$n = \alpha_1 \times d - y_{30} \quad (30 \leq d \leq 1{,}095) \cdots\cdots\cdots\cdots\cdots\cdots \quad (6.2)$$

n: number of organisms that attach per 10,000 mm^2 per day (pieces)

α_1: increasing rate of organism attachment to antifouling painted skin [4 pieces/(1,095-30) day = 0.0038 pieces/day]

y_{30}: value when no organism is attached during the first 30 days = 0.114 (y intercept value)

d: period after leaving dock (days)

The above conditions are based on use of the current antifouling paint with a 3-year antifouling effect. If antifouling paint performance is improved, the attachment-free and antifouling effective periods can be prolonged and the deterioration rate of antifouling performance can be reduced.

Figure 6.1-2 shows dose-dependent changes in the antifouling effect when a ship is processed with the current antifouling paint (3-year effective) - calculated using formulae (6.1) and (6.2).

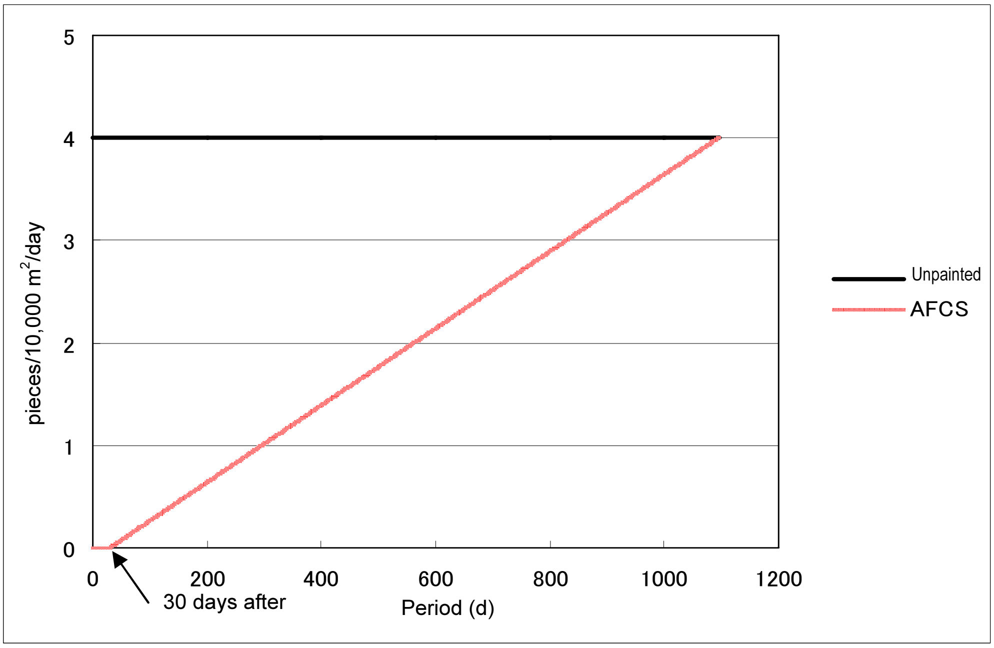


Figure 6.1-2 Dose-dependent changes in the number of early larvae attached when a ship is processed with the current self-polishing system

b) Determination of the falling effect of self-polishing antifouling paint on larvae during shipping

The current technique with 3-year antifouling effect (self-polishing antifouling paint) is considered to be 50% effective on larvae (the percentage of larvae falling off compared to the number of larvae attached per day), decreasing over time to 0% after 3 years. The falling effect is considered to occur during the first shipping for organisms which have become attached while in harbor and any larvae remaining after the end of the first shipping are not considered to be at risk of falling anymore because of the cement layer established around them.

The time-dependent change in numbers of larvae falling off during the period (30≤d≤1,095 days) in which the antifouling paint effect is gradually decreasing is expressed by the following formula:

$$f_{rate} = \beta_1 \times d - f_{ins} \quad (30<d\leq 1{,}095) \cdots\cdots\cdots\cdots\cdots\cdots (6.3)$$

f_{rate}: falling rate = number of organisms falling per day/number of organisms attached
β_1: decreasing falling rate (0.5 [initial falling rate]/1,095 days = 0.00046/day)
f_{ins}: initial falling rate
d: period (days)

The time-dependent change calculated using formula (6.3) is shown in Figure 6.1-3

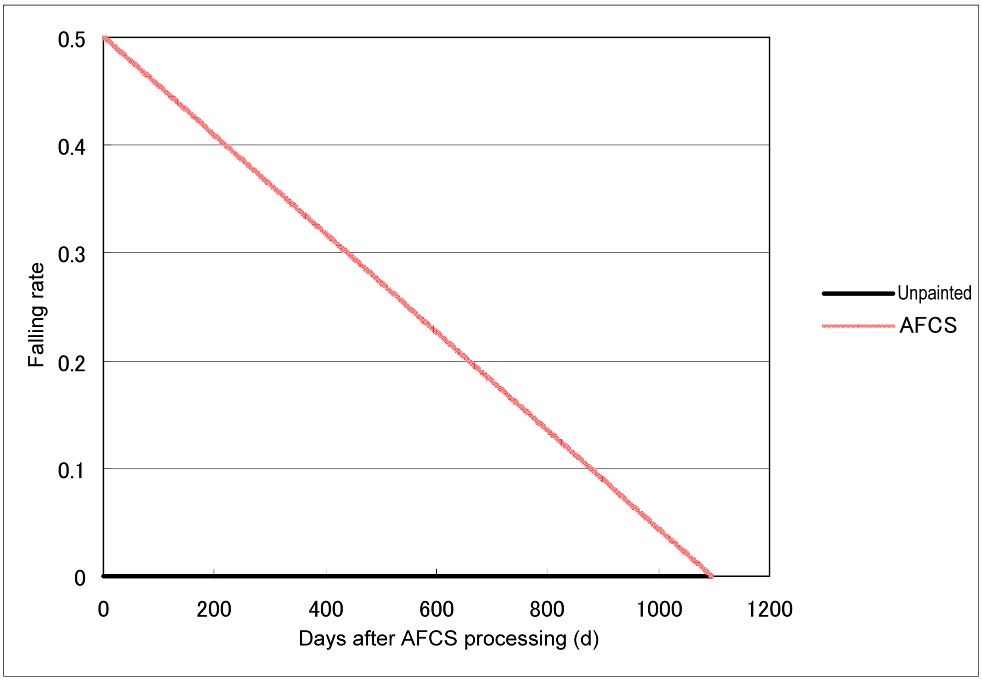


Figure 6.1-3 current self-polishing antifouling paint

c) Determination of the number of organisms attached (taking the falling effect and the antifouling effect into consideration)

The number of organisms attached during the period (30≤d≤1,095 days) during which both the antifouling and larva-falling effects of antifouling paint are gradually decreasing can be expressed by formula (6.5), assuming that the number of organisms attached from days 0 to 30 and after 3 years or more is constant, 0 and 4/day/10,000 mm^2, respectively.

$$n_f = 0 \quad (0 \leq d \leq 30) \cdots\cdots\cdots\cdots (6.4)$$

$$n_f = n - n \times f_{rate} \quad (30 \leq d \leq 1{,}095) \cdots\cdots\cdots\cdots (6.5)$$

$$n_f = 4 \quad (1{,}095 < d) \cdots\cdots\cdots\cdots (6.6)$$

n_f: number of organisms attached per 10,000 mm^2 per day, taking falling into consideration (pieces)
f_{rate}: falling rate
n: number of organisms attached on the day when the antifouling effect of antifouling paint is estimated (pieces)

d) Determination of sexual maturation of biofouling organisms

The number of organisms that grow from larvae through to sexual maturity under the influence of the antifouling and larva-falling effects of the current technique (self-polishing antifouling paint) can be expressed by the following formula:

$$n_{matu} = 0 \quad (0 \leq d \leq 200) \cdots\cdots\cdots\cdots (6.7)$$

$$n_{matu} = \sum_{d=1}^{d=m}\left(\alpha_1 \times d - y_{30}\right) - \sum_{d=m-200}^{d=m}\left(\alpha_1 \times d - y_{30}\right) \qquad (200<d\leq 1{,}095) \cdots\cdots \tag{6.8}$$

= (total number of organisms that attached to a ship body during the larval period and grow for m days) - (number of immature organisms)

where, $0<d\leq 1{,}095$
n_{matu}: number of mature organisms that attached to a ship body during the larval period and grow for m days per 10,000 mm^2 (pieces)
α_1: increasing rate at which organisms attached to antifouling painted skin
y_{30}: value when no organisms are attached during the first 30 days (y intercept value)
d: period after attachment (days)
Constant 200: period of egg maturity (days)

e) Determination of spawning by sexually mature organisms

Spawning by biofouling organisms occurs when sexually mature female organisms (half of the sexually mature organisms present) exist in/near a port during the laying period. Egg production can be expressed by the following formula:

$$s_n = \left(n_{matu}/2\right) \times e_n \cdots\cdots \tag{6.9}$$

$n_{matu}/2$: number of sexually mature female organisms (pieces)
e_n: egg production per sexually mature organism (pieces/day)

Annual egg production

$$s_{nY} = \left(n_{matu}/2\right) \times e_n \times p \cdots\cdots \tag{6.10}$$

s_n: egg production (pieces/day)
s_{nY}: annual egg production (pieces/day)
$n_{matu}/2$: number of sexually mature female organisms (pieces)
e_n: egg production per sexually mature organism (pieces/day)
p: days in harbor during the laying period ($0<p\leq 60$)

f) The number and growing rate of larvae attached, and the attachment area

The standard number and growing rate of larvae attaching to ships were determined for a total area of 10,000 mm^2 (100%) of biofouling during 6 months on an unpainted steel plate that was immersed in a natural sea area that is not affected by self-polishing AFCS in a season when larvae attach to ships .

As specified in the setting conditions used for the model, when organisms attach to hull skin at a rate of 4 pieces/10,000 mm^2/day for two months and grow at a rate of 0.025 mm/day (radius), the accumulated increase in area can be expressed by the following formula:

Until sexual maturation

$$S_1 = \sum_{d=1}^{d=200} n\pi\left[r_i + v_1(d-1)\right]^2 \qquad (1 \le d \le 200) \cdots\cdots\cdots\cdots (6.11)$$

After sexual maturation

$$S_2 = S_1 + \sum_{d=200}^{d=1095} n\pi\left[r_i + v_2(d-1)\right]^2 \qquad (200 < d \le 1{,}095) \cdots\cdots\cdots\cdots (6.12)$$

S_1: accumulated attachment area until sexual maturation (mm^2)
S_2: accumulated attachment area, including the period after sexual maturation (mm^2)
n: number of organisms attached per day (pieces)
r_i: radius of the organism in the early attachment period (mm)
v_1: daily growth rate until sexual maturation (mm/day)
v_2: daily growth rate after sexual maturation (mm/day)
d: period after development (days)
$d = 200$: period until sexual maturation (days)
$d = 1{,}095$: period until next dock visit (days)

Based on the specified number and growing rate of larvae attached, as shown in Figure 6.1-4, the accumulated biofouling area of unpainted steel plate was estimated to be 10,000 mm^2 (i.e., 100% covered) after 170 days.

Figure 6.1-4 Time-dependent change in the accumulated biofouling area of unpainted steel plate

(3) Calculation cases used to assess the risk of species transfer

Table 6.1-2 shows the calculation cases evaluated.

The respective parameters and calculation formulae used in the calculation cases shown are specified in the Data Section (Data-3).

Items compared as part of the estimation process included the current technique, improved technique, new technique and a special shipping pattern (offshore waiting).

Table 6.1-2 Calculation cases and outline of calculation conditions

Technique and shipping conditions		Case No.	Objective of calculation	Outline of calculation conditions[*1]
Current technique		1	Effect of 3-year effective antifouling paint	antifouling paint (3-year effective, no attachment for 30 days after leaving dock)
		1'	Used in assessing the effectiveness of the seawater electrolysis system.	antifouling paint (3-year effective, no attachment for 30 days after leaving dock), falling rate is revised to 10%.
		2	Effect of 2-year effective antifouling paint	antifouling paint (2-year effective, no attachment for 30 days after leaving dock)
		3	Effect of 1-year effective antifouling paint	antifouling paint (1-year effective, no attachment for 30 days after leaving dock)
Improved technique and new technique	antifouling paint	4	Effect of high-performance antifouling paint (1)	antifouling paint (5-year effective, no attachment for 30 days after leaving dock)
		5	Effect of high-performance antifouling paint (2)	antifouling paint (5-year effective, no attachment for 90 days after leaving dock)
	IWC	6	Effect of IWC implementation	Case 1 + IWC (implementation every year)
		7	Effect of IWC implementation in specified countries	Case 1 + IWC (implementation in one of the countries every year)
		8	Effect of reduced interval of IWC implementation	Case 1 + IWC (implementation every 0.5 years)
		9	Effect of collection of IWC-removed materials	Case 1 + IWC (implementation every year, collection of removed materials)
	Seawater electrolysis system	10	Effect of seawater electrolysis system	Case 1 + seawater electrolysis system (falling rate: 10% decrease in the maximum number of larvae per day)
		11	Effect of seawater electrolysis system + IWC	Case 6 + seawater electrolysis system (falling rate: 10% decrease in the maximum number of larvae per day)
Offshore waiting		12	Effect of a prolonged anchoring period due to offshore waiting	Case 1 + offshore waiting (14-day offshore waiting period for shipping)
		13	Effect of IWC implementation in the other country (with offshore waiting)	Case 6 + offshore waiting (14-day offshore waiting period for shipping)

*1: The respective calculation conditions and formulae (except the basic formulae) are included in the Data Section (Data-3) since different calculation formulae were used depending on the calculation conditions. The calculation results are also included in the Data Section (Data-4).

6.2 Assessment of the effect of different application techniques on the risk of organism transfer

6.2.1 Anti-fouling system (AFS)

(1) Evaluation of the anti-fouling coating system (AFCS)

a) Evaluation of AFCS currently in use

Self-polishing AFCS is commonly used in antifouling paints currently applied to the outer hull skin to prevent biofouling.

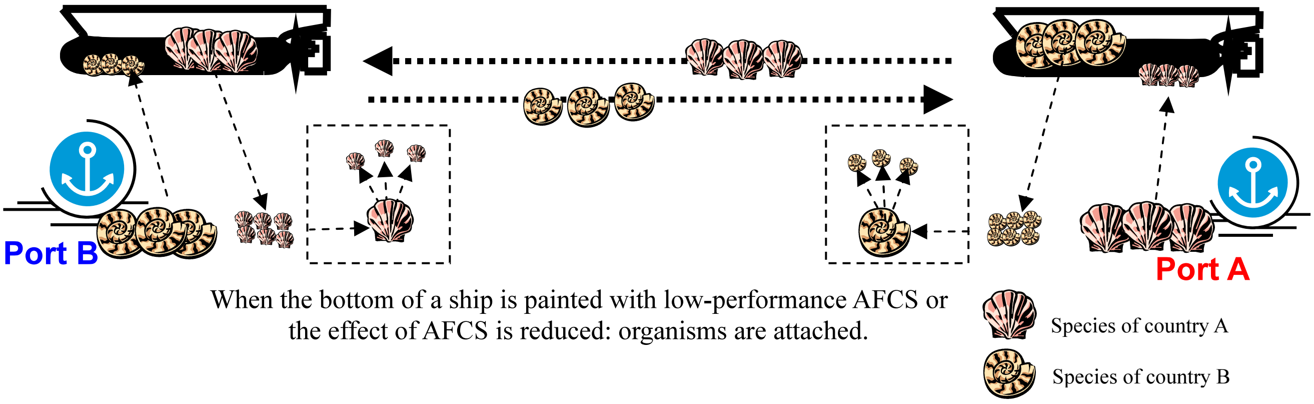
Current self-polishing antifouling paints are designed to have a 3- or 5-year antifouling effect. This period is meant to correspond to the interval between dock visits for cleaning (5 years) and interim inspection (2.5 years). Almost all ships in Japan enter dock at 2.5-year intervals and surface cleaning is carried out on almost all ships for antifouling purposes. The fact that a ship has to enter dock for cleaning at 2.5-year intervals indicates that organisms are already attached to the hull skin by this time. Consequently, it is suspected that the current self-polishing antifouling paints do not provide the antifouling performance they were designed for, due to various practical considerations and conditions encountered in the field. Therefore, to estimate such conditions using a model, the current technique designed with a 3-year effective antifouling performance (self-polishing antifouling paint) was compared with self-polishing antifouling paints with 1- and 2-year effective antifouling performance.

Current antifouling paint is evaluated on the basis of the standards for 3-year effective antifouling performance and compared with antifouling paints with 1- and 2-year effective antifouling performance.

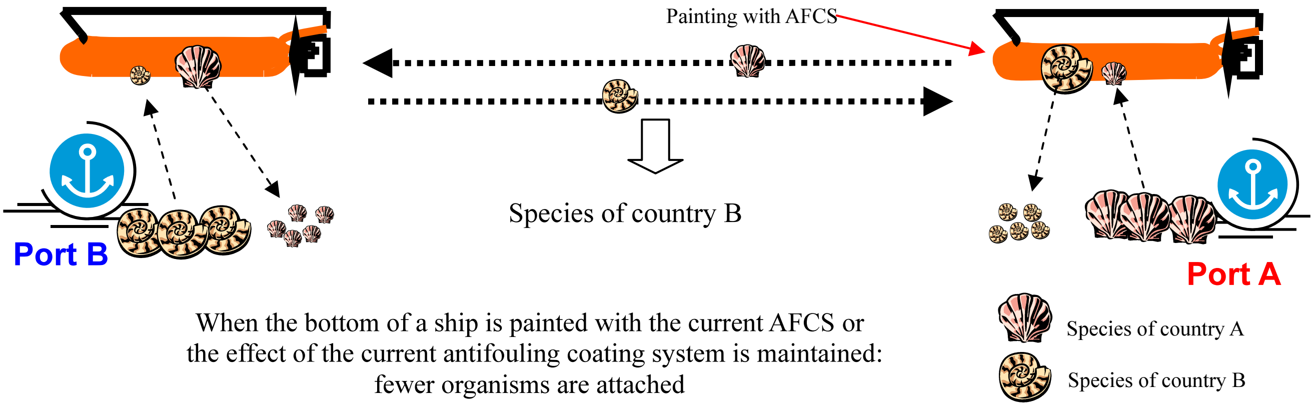
Table 6.2-1 Evaluation of the effect of antifouling paint currently in use

Objective of evaluation	Standard case (Calculation case 1)	Test case evaluated (Calculation cases 2 and 3)
Evaluation of current antifouling paint	Current technique (self-polishing antifouling paint with 3-year effective antifouling performance)	Low-performance technique (self-polishing antifouling paint with 1- or 2-year effective antifouling performance)

The decreasing effect of self-polishing antifouling paint on egg production is illustrated in Figure 6.2-1. The upper diagram shows the case of a ship treated with low-performance antifouling paint, while the bottom diagram shows the case of a ship treated with the current technique (self-polishing antifouling paint with 3-year performance). As the larva tries to attach itself to the ship in harbor, it seeks to avoid the active substance in the antifouling paint, resulting in failure to attach. antifouling paint has a further effect in removing (by flow pressure) those larvae already attached in harbor but not yet fixed firmly in place. Larvae remaining after the end of the first shipping are considered not to be at risk of falling anymore because a cement layer has been established around them.



When the bottom of a ship is painted with low-performance AFCS or the effect of AFCS is reduced: organisms are attached.



When the bottom of a ship is painted with the current AFCS or the effect of the current antifouling coating system is maintained: fewer organisms are attached

Figure 6.2-1 The effect of antifouling paint on egg production

The annually accumulated number of sexually mature organisms that are attached to the outer hull skin of ships processed using current techniques with 3-year effective antifouling performance (self-polishing antifouling paint) or self-polishing antifouling paint with 1- or 2-year effective antifouling performance, and which then spawn, is shown in Table 6.2-2. The annually accumulated egg production from these sexually mature organisms is shown in Table 6.2-3 The ratios of accumulated egg production in the test cases compared to the standard case (set at 1) are shown in Table 6.2-4. The accumulated egg production was calculated for the 3 years from leaving dock until returning to dock for cleaning. In the settings used for this basic model, the number of organisms attached in country A was equal to that in country B. Consequently, the accumulated egg production in country B from organisms attached in country A was equal to that in country A from organisms attached in country B.

The accumulated egg production in the case of the current technique (self-polishing antifouling paint: 3-year effective) was estimated to be of the order of 10^3 pieces/10,000 mm^2 one year after leaving dock, 10^4 pieces/10,000 mm^2 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 3 years after leaving dock.

In contrast, the accumulated egg production in the case of the low-performance self-polishing antifouling paint (1- or 2-year effective) was estimated to increase approximately 1.5- to 2.5-fold compared with the current self-polishing antifouling paint treatment (3-year effective). The mean antifouling performance for antifouling paints with 1-, 2- and 3-year effectiveness was 2×10^3 pieces/10,000 mm^2 one year after leaving dock, 8×10^4 pieces/10,000 mm^2 2 years after leaving dock and 4×10^5 pieces/10,000 mm^2 3 years afterwards, respectively.

The dose (3-year accumulated egg production) in the case of a ship processed with the 1-year effective antifouling paint was estimated to be 243% the size of the dose obtained in the standard case whereas, in the case of a ship processed with the 2-year effective antifouling paint the dose was estimated to be only 150% of the standard value, and in the case of a ship processed with 1-, 2- and 3-year effective antifouling paint (evenly mixed) it was estimated to be 164% of the standard value.

Therefore, it was shown that various currently used antifouling paints were associated with different levels of risk for organism transfer. Since ships processed with low-performance antifouling paint are still in service, the risk of organism transfer will be reduced if these ships are processed with high-performance antifouling paint instead.

Table 6.2-2 Annually accumulated number of mature organisms attached to hull skin processed with the current technique (self-polishing antifouling paint) and low-performance antifouling paint, and which then spawn [*1]

Unit: pieces/10,000 mm^2/year

Period	Standard case (Case 1) Current technique (self-polishing antifouling paint with 3-year effective antifouling performance)	Low-performance antifouling paint (Case 2, 3)		Mean (effective antifouling performance period: 1-3 years)
		antifouling paint with 2-year effective antifouling performance (Case 2)	antifouling paint with 1-year effective antifouling performance (Case 3)	
Year 0 to 1	0.3	0.5	1.1	0.6
Year 1 to 2	9.4	14.2	27.3	17.0
Year 2 to 3	50.3	75.3	117.6	81.1

The number of sexually mature individuals in country A is the same as that in country B.

*1: total number of organisms per unit area per year

Table 6.2-3 Accumulated egg production of mature organisms on hull skin processed with the current technique (self-polishing antifouling paint) and low-performance antifouling paint. (Total accumulated egg production by sexually mature organisms)

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case (Case 1) Current technique (self-polishing antifouling paint with 3-year effective antifouling performance)	Low-performance antifouling paint (Case 2, 3)		Mean (effective antifouling performance period: 1-3 years)
		antifouling paint with 2-year effective antifouling performance (Case 2)	antifouling paint with 1-year effective antifouling performance (Case 3)	
1 year	1.56×10^3	2.37×10^3	4.94×10^3	2.95×10^3
2 years	4.51×10^4	6.86×10^4	1.32×10^4	8.18×10^4
3 years	2.79×10^5	4.18×10^5	6.78×10^5	4.59×10^5

Total accumulated egg production in country A is the same as that in country B.

Table 6.2-4 The ratios of accumulated egg production in low-performance antifouling paint cases to that in the standard case

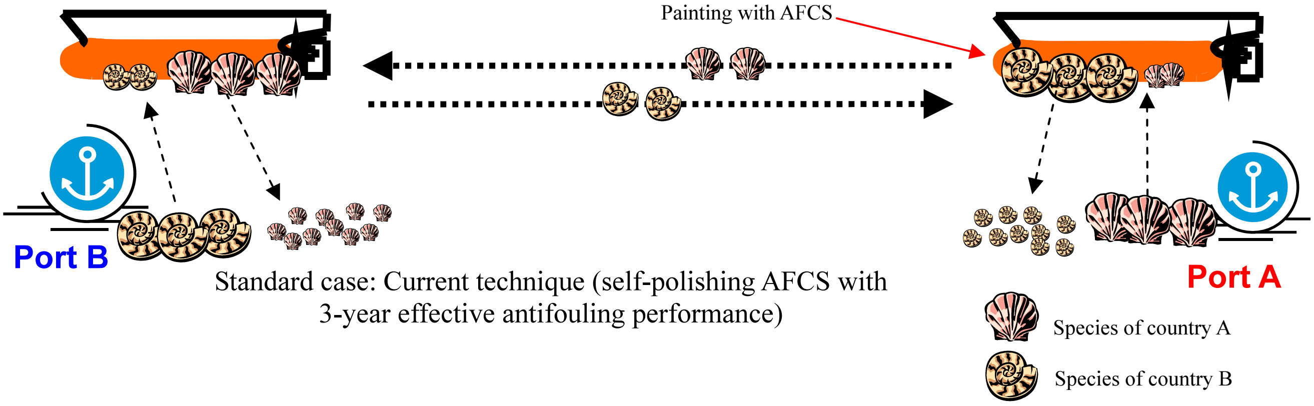
Period after leaving dock (years)	Standard case (Case 1) Current technique (self-polishing antifouling paint with 3-year effective antifouling performance)	Low-performance antifouling paint (Case 2, 3)		Mean (effective antifouling performance period: 1-3 years)
		antifouling paint with 2-year effective antifouling performance (Case 2)	antifouling paint with 1-year effective antifouling performance (Case 3)	
1 year	1	1.52	3.18	1.90
2 years	1	1.52	2.92	1.81
3 years	1	1.50	2.43	1.64

b) Evaluation of high-performance antifouling paint

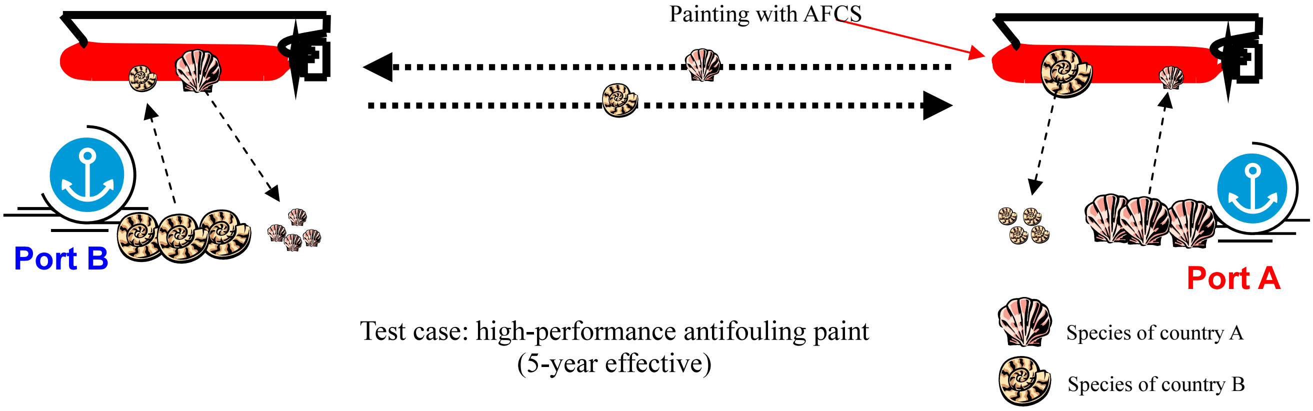
The high-performance antifouling paint is designed to maintain an antifouling effect for 5 years, whereas the current technique (self-polishing antifouling paint) is designed to maintain an antifouling effect for only 3 years. The test case used to evaluate high-performance antifouling paint use was subdivided into 2 variants: no attachment of larvae for either 30 or 90 days immediately after leaving dock. The current technique (3-year effective self-polishing antifouling paint) was considered to be the standard case for comparative estimation (Table 6.2-5). The effect of high-performance antifouling paint on egg production is shown in Figure 6.2-2.

Table 6.2-5 Evaluation of the effect of high-performance antifouling paint

Objective of evaluation	Standard case (Calculation case 1)	Case to evaluate (Calculation cases 4 and 5)
Effect of high-performance antifouling paint	Current technique (self-polishing antifouling paint with 3-year effective performance)	(1) High-performance antifouling paint (antifouling paint with 5-year effective antifouling performance and no attachment for 30 days after leaving dock). (Calculation case 4)
		(2) High-performance antifouling paint (antifouling paint with 5-year effective antifouling performance and no attachment for 90 days after leaving dock). (Calculation case 5)



Standard case: Current technique (self-polishing AFCS with 3-year effective antifouling performance)



Test case: high-performance antifouling paint (5-year effective)

Figure 6.2-2 The effect of high-performance antifouling paint on egg production

The annually accumulated number of sexually mature organisms that are attached to the outer hull outer skin and spawn there is shown in Table 6.2-6. The annually accumulated egg production from these sexually mature organisms is shown in Table 6.2-7. Done by T. The ratios of accumulated egg production in the test cases to that of the standard case (set at 1) are shown in Table 6.2-8. Accumulated egg production was calculated for 3 years from leaving dock until returning to dock.

The accumulated egg production in the case of the high-performance self-polishing antifouling paint was estimated to be of the order of 10^2 pieces/10,000 mm^2 (no attachment for 30 days after leaving dock) and 10^1 pieces/10,000 mm^2 (no attachment for 90 days after leaving dock) one year after leaving dock, 10^3 pieces/10,000 mm^2 in both cases for 2 years after leaving dock, and 10^4 pieces/10,000 mm^2 in both cases for 3 years after leaving dock.

The dose (3-year accumulated egg production) in the case of a ship processed with the high-performance antifouling paint without attachment for 30 days after leaving dock was estimated to be 20.7% the size of the dose used in the standard case whereas, in the case of a ship processed with the high-performance antifouling paint without attachment for 90 days the dose was estimated to be 18.3%, showing a significant reduction in attachment by approximately one fifth in comparison to the current self-polishing antifouling paint. These results suggest that any improvement in self-polishing antifouling paint would contribute to a reduction in accumulated egg production by biofouling organisms, and that this would be an effective means of reducing the risk of organism transfer. Egg production was compared in cases where there was no attachment for 30 and 90 days after leaving dock. The level of

1-year egg production, in the case with no attachment for 30 days after leaving dock, increased 3-fold compared to the case with no attachment for 90 days. However, the level of 3-year egg production was not markedly different between the two cases.

These results indicate that improvement in the initial performance of antifouling paint reduces the risk of organism transfer for 1 or 2 years after leaving dock. Therefore, the performance of antifouling paint should be evaluated with due consideration for the aims of antifouling paint use. For example, a soaking test using plates with painted surfaces exposed to artificial age-related degradation would be useful for evaluation purposes.

Table 6.2-6 Annually accumulated number of sexually mature organisms attached to hull skin processed with the current and high-performance antifouling paint, and which then spawn[*1]

Unit: pieces/10,000 mm^2

Period	Standard case (Calculation case 1)	High-performance antifouling paint (Calculation cases 4, 5)	
	Standard case Current technique (self-polishing antifouling paint with 3-year effective performance)	High-performance antifouling paint -1 (5-year effective antifouling performance, larval attachment-free period for the first 30 days after leaving dock). (Calculation case 4)	High-performance antifouling paint -2 (5-year effective antifouling performance, larval attachment-free period for the first 90 days after leaving dock). (Calculation case 5)
Year 0 to 1	0.3	0.0	0.0
Year 1 to 2	9.4	1.5	1.2
Year 2 to 3	50.3	10.9	9.8

The number of sexually mature individuals in country A is the same as that in country B.

*1: total number of organisms per unit area per year

Table 6.2-7 Accumulated egg production by sexually mature organisms attached to hull skin processed with the current and high-performance antifouling paint

Unit: egg production/10,000 mm^2

Years after leaving dock	Standard case (Calculation case 1)	High-performance antifouling paint (Calculation cases 4, 5)	
	Standard case Current technique (self-polishing antifouling paint with 3-year effective performance)	High-performance antifouling paint -1 (5-year effective antifouling performance, larval attachment-free period for the first 30 days after leaving dock). (Calculation case 4)	High-performance antifouling paint -2 (5-year effective antifouling performance, larval attachment-free period for the first 90 days after leaving dock). (Calculation case 5)
1 year	1.56×10^3	100	29.0
2 years	4.51×10^4	6.85×10^3	5.60×10^3
3 years	2.79×10^5	5.78×10^4	5.11×10^4

Accumulated egg production in country A is the same as that in country B.

Table 6.2-8 The ratios of accumulated egg production in high-performance antifouling paint cases to that in the standard case

Years after leaving dock	Standard case (Calculation case 1)	High-performance antifouling paint (Calculation cases 4, 5)	
	Standard case Current technique (self-polishing antifouling paint with 3-year effective performance)	High-performance antifouling paint -1 (5-year effective antifouling performance, larval attachment-free period for the first 30 days after leaving dock) (Calculation case 4)	High-performance antifouling paint -2 (5-year effective antifouling performance, larval attachment-free period for the first 90 days after leaving dock) (Calculation case 5)
1 year	1	0.064	0.019
2 years	1	0.152	0.124
3 years	1	0.207	0.183

(2) Evaluation of marine growth prevention systems (MGPS)

The seawater electrolysis system, a common MGPS used for components except hull skin, is currently used for the inner piping system of ships. The effectiveness of the seawater electrolysis system was evaluated when it was applied to the sea chest.

a) Evaluation of the current seawater electrolysis system

Seawater electrolysis systems are currently used for the inner piping system of ships but not for the sea chest on which biofouling is severe. Since there are no reports of a seawater electrolysis system being applied to a sea chest, the following suggestions have been based on its current use for inner piping systems.

As shown in Section 3.3.1 (2), no quantitative data are available for the antifouling effect of seawater electrolysis systems. According to the specifications provided for the current seawater electrolysis system, the residual chlorine concentration is 0.3 mg/L, which is similar to the acute toxicity value of residual chlorine for marine organisms. However, the release concentration is designed to be low (between 0.02 and 0.05 mg/L) and the exposure time is expected to be short. Consequently, the effect of the seawater electrolysis system may only be a transient reduction in the attachment function of organisms present.

b) Evaluation of the future seawater electrolysis system

The effect of the seawater electrolysis system, alone, and the effect of a combined IWC system and a seawater electrolysis system were both evaluated.

i) Effect of the seawater electrolysis system, alone

The standard case was assumed to be where the seawater electrolysis system was not applied to the sea chest, and this was compared with the test case where a seawater electrolysis system was used. Taking the slow flow rate found in the sea chest in the standard and test cases into consideration, the initial falling rate was set at 10% (Table 6.2-9).

Table 6.2-9 Evaluation of the effect of future seawater electrolysis systems on egg production

Objective of evaluation	Standard case (Calculation case 1')	Test case evaluated (Calculation case 10)
Effect of the seawater electrolysis system	The current technique (antifouling paint with 3-year performance) was applied and the initial falling rate was reduced to 10%, in consideration of the slow flow rate.	Application of the seawater electrolysis system in addition to the antifouling paint

The annually accumulated number of sexually mature organisms that are attached to the sea chest and spawn there is shown in Table 6.2-10. The annually accumulated egg production from these sexually mature organisms is shown in Table 6.2-11. The ratio of the accumulated egg production in the test case to that in the standard case is shown in Table 6.2-12. The accumulated egg production was calculated for 3 years from leaving dock until returning to dock. In terms of the setting conditions used for this basic model, the number of organisms attached in country A was equal to that in country B. Consequently, the accumulated egg production in country B from organisms attached in country A was equal to that in country A from organisms attached in country B.

The accumulated egg production for the current technique (self-polishing antifouling paint: 3-year effective) was estimated to be in the order of 10^3 pieces/10,000 mm^2 one year after leaving dock, 10^4 pieces/10,000 mm^2 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 3 years after leaving dock. In contrast, the seawater electrolysis system reduced the dose (3-year accumulated egg production) to 94.6% of the value obtained using the current technique alone (self-polishing antifouling paint with 3-year performance).

The reason for this was considered to be due to the parameter settings. Use of the current technique (self-polishing antifouling paint with 3-year performance) assumed that, after processing, organisms were not attached for 30 days after leaving dock and then gradually increased in number at a maximum rate of 4 pieces/day/10,000 mm^2 for 3 years. On the other hand, the use of the seawater electrolysis system assumed that the chloride compound released from the system was only 50% as effective as the current technique (self-polishing antifouling paint with 3-year performance). Based on these assumptions, the number of organisms attached was only 2 pieces/day/10,000 mm^2 (50% of the current technique). Consequently, the current antifouling paint had a superior antifouling effect to the seawater electrolysis system for up to 600 days after leaving dock, during which time the seawater electrolysis system had almost no effect for approximately 2 years after leaving a dock.

Based on these results, when applying the seawater electrolysis system to a sea chest with severe biofouling it can be seen that the concentration of chloride compound used to support the antifouling effect of antifouling paint has little or no effect. It is necessary to increase the concentration to 3 mg/L, the maximum allowable concentration in consideration of chemical environmental risks. However, even though the seawater electrolysis system had only a slight effect on accumulated egg production, as shown above, it is a promising measure to consider for future use on the sea chest, for which no effective measures have yet been established. To use the seawater electrolysis system for sea chests, it will be necessary to determine the most appropriate concentration of chloride compound to inject, and develop a suitable technique to distribute chloride all over the wall of the sea chest and to either continuously or intermittently inject the compound while the ship is in the harbor. If these techniques can be successfully developed the seawater electrolysis system could be a promising means of reducing egg production in those sites with the most frequent biofouling.

Table 6.2-10 The annually accumulated number of sexually mature organisms that are attached to the sea chest and spawn there when antifouling paint with a decreased falling rate [*1] and a combination of antifouling paint with a decreased falling rate and a seawater electrolysis system [*2] are used

Unit: pieces/10,000 mm^2/year

Period	Standard case (Calculation case 1') (antifouling paint in which the falling rate decreased)	Application of the seawater electrolysis system in addition to the conditions specified in the left-hand column (Calculation case 10)
Year 0 to 1	0.6	0.6
Year 1 to 2	13.6	13.6
Year 2 to 3	65.9	61.6

The number of sexually mature individuals in country A is the same as that in country B.

*1: antifouling paint, assuming that the current technique (self-polishing antifouling paint) is applied to a sea chest and that the falling rate immediately after leaving dock decreased from 50% to 10% for 3years, in consideration of the slow flow rate in the sea chest.

*2: total number of organisms per unit area per year

Table 6.2-11 The accumulated number of sexually mature organisms that are attached to the sea chest and spawn when antifouling paint with a decreased falling rate [*1] and a combination of antifouling paint with decreased falling rate and the seawater electrolysis system are used

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case (Calculation case 1') (antifouling paint in which the falling rate decreased)	Application of the seawater electrolysis system in addition to the conditions specified in the left-hand column (Calculation case 10)
1 year	2.57×10^3	2.57×10^3
2 years	6.57×10^4	6.57×10^4
3 years	3.72×10^5	3.52×10^5

Accumulated egg production in country A is the same as that in country B.

*1: antifouling paint, assuming that the current technique (self-polishing antifouling paint) is applied to the sea chest and that the falling rate immediately after leaving dock decreased from 50% to 10% for 3 years, in consideration of the slow flow rate in the sea chest.

Table 6.2-12 The ratio of accumulated egg production in the test case (antifouling paint + seawater electrolysis system) to that in the standard case

Period after leaving dock (years)	Standard case: antifouling paint in which the falling rate decreased (Calculation case 1')	Application of the seawater electrolysis system in addition to the conditions specified in the left-hand column (Calculation case 10)
1 year	1	1
2 years	1	1
3 years	1	0.946

ii) Effect of the combination of the seawater electrolysis system and IWC

The effect of applying a combination of the seawater electrolysis system and IWC (without collection of removed materials) to the sea chest was evaluated. The standard case used was that in which a seawater electrolysis system was not applied to the sea chest.

Table 6.2-13 Evaluation of the effect of a combination of the seawater electrolysis system and IWC on egg production

Objective of evaluation	Standard case (Calculation case 1')	Test case evaluated (Calculation case 11)
Effect of a combination of the seawater electrolysis system and IWC	The current technique (antifouling paint with 3-year performance) was applied and the initial falling rate was decreased to 10%, in consideration of the slow flow rate.	A combination of antifouling paint, as specified in the left-hand column, a seawater electrolysis system and IWC (removed materials were not collected)

The annually accumulated number of sexually mature organisms that are attached to a sea chest and spawn there is shown in Table 6.2-14. The annual accumulation of egg production from these sexually mature organisms is shown in Table 6.2-15. The ratio of accumulated egg production in the test case to that in the standard case is shown in Table 6.2-16. Accumulated egg production was calculated for 3 years from leaving dock until returning to dock. In the settings used for this basic model, the number of organisms attached in country A was equal to that in country B. Consequently, the accumulated egg production in country B from organisms attached in country A was equal to that in country A from organisms attached in country B.

The accumulated egg production, i.e., the total egg production from organisms that attached to the hull skin after IWC implementation and from organisms that were removed and dispersed into the sea area by IWC, was estimated to be in the order of 10^3 pieces/10,000 mm^2 one year after leaving dock, 10^4 pieces/10,000 mm^2 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 3 years after leaving dock. The dose (3-year accumulated egg production) for the combination of the seawater electrolysis system and IWC was 91% of the standard value and not significantly different from the result achieved with the seawater electrolysis system alone (94.6%). However, in the test case evaluated, the number of organisms that attached to the hull skin after IWC implementation and the number of organisms removed and dispersed into the sea area by IWC were different from those of the standard case. The former was only 13.7% as high as the standard case and the latter was 77.3% as high as the standard case (IWC-removed materials were not collected). Since the percentage of organisms removed and dispersed into the sea area could be decreased further by the collection of removed materials, IWC could be considered a promising option when part of a combined technique applied to sea chests.

Table 6.2-14 The annually accumulated number of sexually mature organisms that are attached to the sea chest and spawn there, after use of antifouling paint with a decreased falling rate [*1] and antifouling paint with a decreased falling rate + seawater electrolysis system + IWC[*2]

Unit: pieces/10,000mm^2/year

Period	Standard case: antifouling paint with a decreased falling rate (Calculation case 1')	In addition to antifouling paint with a decreased falling rate, the seawater electrolysis system is applied and IWC[*3] is implemented. (Calculation case 11)	
		The annual number of sexually mature organisms which attached to hull skin after IWC implementation and grew there	The number of organisms that were removed and dispersed into the sea area by IWC and which survived and reached sexual maturity (not collected with a net)
Year 0 to 1	0.6	0.3	0.0
Year 1 to 2	13.6	4.2	3.4
Year 2 to 3	65.9	6.4	58.5

The number of sexually mature individuals in country A is the same as that in country B.

[*1]: Antifouling coating system, assuming that the current technique (self-polishing antifouling paint) is applied to the sea chest and that the falling rate immediately after leaving dock decreased from 50% to 10% for 3 years, in consideration of the slow flow rate in the sea chest.

[*2]: total number of organisms per unit area per year

[*3]: IWC is implemented at one-year intervals in the port of the country which a ship enters just under one year after leaving dock.

Table 6.2-15 Accumulated egg production by sexually mature organisms that are attached to the sea chest and spawn there, after use of antifouling paint with a decreased falling rate [*1] and antifouling paint with a decreased falling rate + seawater electrolysis system + IWC

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case: antifouling paint with a decreased falling rate (Calculation case 1')	In addition to antifouling paint with a decreased falling rate, the seawater electrolysis system is applied and IWC is implemented (Calculation case 11)		
		(a) Egg production by organisms that attached to hull skin after IWC implementation	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC (not collected with a net)	Total (a) + (b)
1 year	2.57×10^3	1.56×10^3	0.0	1.56×10^3
2 years	6.57×10^4	2.13×10^4	1.60×10^4	3.73×10^4
3 years	3.72×10^5	5.11×10^4	2.88×10^5	3.39×10^5

Accumulated egg production in country A is the same as that in country B.

[*1]: antifouling paint, assuming that the current technique (self-polishing antifouling paint) is applied to the sea chest and that the falling rate immediately after leaving dock decreased from 50% to 10% for 3 years, in consideration of the slow flow rate in the sea chest.

Table 6.2-16 The ratio of accumulated egg production in the test case (antifouling paint + seawater electrolysis system + IWC) to that in the standard case

Period after leaving dock (years)	Standard case: antifouling paint with a decreased falling rate. (Calculation case 1')	In addition to antifouling paint with a decreased falling rate, the seawater electrolysis system is applied and IWC is implemented (Calculation case 11)		
		(a) Egg production by organisms that attached to hull skin after IWC implementation	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC (not collected with a net)	Total (a) + (b)
1 year	1	0.604	0	0.604
2 years	1	0.324	0.244	0.568
3 years	1	0.137	0.773	0.910

6.2.2 Removal technique for biofouling organisms

IWC was evaluated as a removal technique for biofouling organisms. Implementation of the current IWC technique was examined first, and the effectiveness of future IWC systems was then estimated.

(1) Evaluation of the current IWC technique

The current IWC technique is generally used to reduce the extra friction and drag at sea caused by attached organisms on the outer hull and to prevent any increase in fuel consumption due to biofouling (see Section 4.3.1).

Therefore, the current IWC technique aims to completely remove all organisms firmly attached to the outer hull in order to increase the fuel efficiency. The survey results in March 2010 showed that IWC was performed using an extremely hard brush such as a swaging brush (a wire brush) due to severe biofouling. As a result, almost all organisms were removed. However, it was also confirmed that coating layers were simultaneously removed and that the use of a wire brush (including a swaging brush) did a great deal of damage to the antifouling paint.

In most (approximately 90%) of the facilities currently implementing IWC, a soft nylon brush is also used and a wire brush is only applied to those areas where biofouling is severe (approximately 10%) (see Section 4.3.1).

The materials removed by IWC are usually not collected but released (dispersed) into surrounding sea areas. In very few facilities, the material removed is collected with a net, landed and treated as industrial waste for disposal purposes (see Section 4.3.1).

(2) Evaluation of future IWC systems

If a convention on antifouling control is established, IWC may be implemented in all countries. Based on this assumption, IWC will be performed in the future as a means of reducing the risk of biofouling by organisms and as a preventive measure to offset increased fuel consumption. The effectiveness of IWC in reducing the risk of organism transfer was, therefore, evaluated by estimating egg production in relation to IWC frequency, site (country), interval, collection of removed materials, and collection size.

After IWC, spawning occurs via 2 possible routes. The first route involves spawning by sexually mature organisms that have been dispersed into the sea area by IWC and have survived in the sea bed, and immature organisms that have been similarly dispersed and have survived until they reached sexual maturity. The amount of egg production via this route is relatively large because the organisms surviving in the sea bed spawn continuously throughout the egg-laying period until they die. This is one factor leading some countries to have a negative opinion of IWC.

The second route involves spawning in another country by organisms that have attached themselves to the hull skin after IWC implementation and then reach sexual maturity and spawn on the hull during this country's egg-laying period.

The overall amount of egg production associated with IWC implementation is the combined total of these 2 routes.

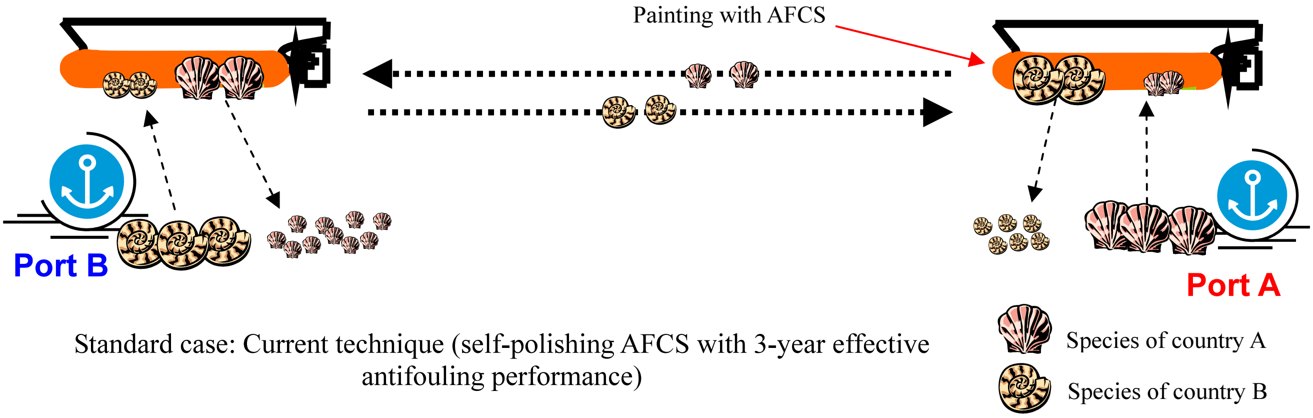
a) Evaluation of the effect of IWC on egg production

The effect of IWC on the egg production is shown in Figure 6.2-3. If IWC is not implemented, sexually mature organisms attached to the hull skin can spawn in a distant port. In contrast, if IWC is implemented, organisms that have attached themselves to the hull skin after IWC do not spawn before they reach sexual maturity. The effect of IWC was evaluated by comparing accumulated egg production for the current technique (self-polishing antifouling paint with 3-year performance, IWC not applied) with that after IWC implementation at one-year intervals. The conditions set for IWC implementation were that IWC-removed materials were not collected and that all organisms in the removed materials were dispersed into sea areas.

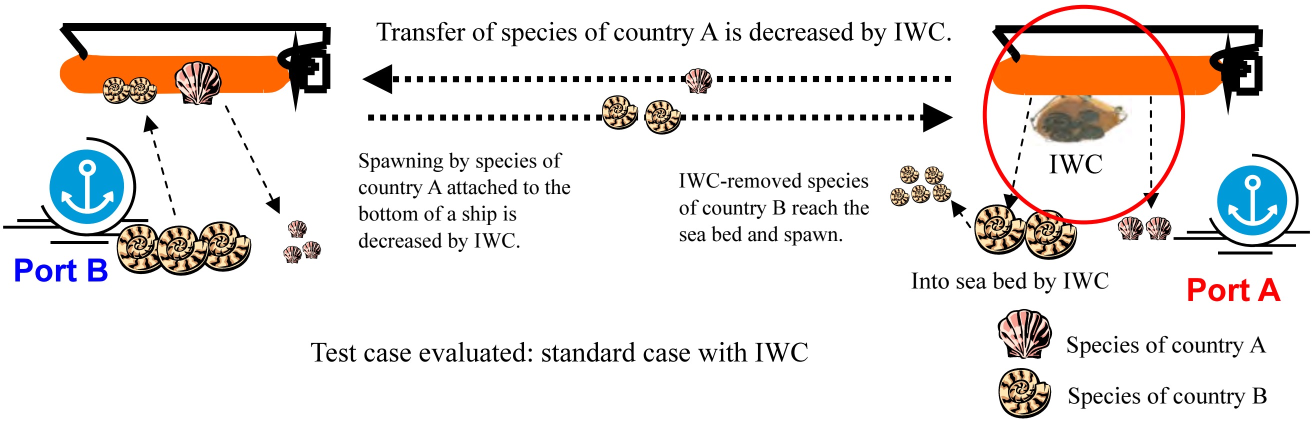
Table 6.2-17 Evaluation of the effect of IWC on egg production

Objective of evaluation	Standard case (Calculation case 1)	Test case evaluated (Calculation case 6)
Effect of IWC implementation	Current technique (self-polishing antifouling paint with 3-year effective performance)	IWC was implemented on outer skin processed with the current technique (self-polishing antifouling paint) at 1-year intervals (removed materials were not collected).

Table 6.2-18 shows the annually accumulated number of sexually mature organisms that were attached to hull skin and spawned there, organisms that were attached to hull skin after IWC implementation and reached sexual maturity and spawned there, and organisms that were removed and dispersed into the sea area by IWC and survived to reach sexual maturity. The annual accumulation of egg production from these sexually mature organisms is shown in Table 6.2-19. The ratio of accumulated egg production in the test cases to that of the standard case is shown in Table 6.2-20. Accumulated egg production was calculated for 3 years from leaving dock until returning to dock. In the setting conditions used for this basic model, the number of organisms attached in country A was equal to that in country B. Consequently, the accumulated egg production in country B from organisms attached in country A was equal to that in country A from organisms attached in country B.



Standard case: Current technique (self-polishing AFCS with 3-year effective antifouling performance)



Test case evaluated: standard case with IWC

Figure 6.2-3 The effect of IWC on egg production

Accumulated egg production, i.e., total egg production from organisms that attached to hull skin after IWC implementation and from organisms that were removed and dispersed into the sea area by IWC, was estimated to be of the order of 10^3 pieces/10,000 mm^2 for one year after leaving a dock, 10^4 pieces/10,000 mm^2 for 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 for 3 years after leaving dock. The dose (3-year accumulated egg production) in the case of a ship processed with IWC was estimated to be 95.3% of the dose obtained in the standard case: the current technique (self-polishing antifouling paint) without IWC.

In practice, current antifouling paint performance is less than the performance originally specified by the manufacturer. Therefore, any additional biofouling risk due to the use of IWC to remove attached materials was estimated to be low. Consequently, it is not necessary to immediately ban IWC. However, if antifouling paint performance is sufficiently maintained for a long period of time in actual sea areas, an additional biofouling risk due to IWC cannot be ruled out and it will be necessary to take specific measures to prevent egg production, such as the collection of removed materials.

The breakdown of the 95.3% figure cited above comprises 22.8% from egg production by organisms that attached to hull skin after IWC implementation and 72.4% from organisms that were removed and dispersed into the sea area by IWC (without collection). This result suggests that the collection of IWC-removed materials substantially reduces the risk of organism transfer.

Table 6.2-18 The annually accumulated number of organisms that are attached after use of the current technique (self-polishing antifouling paint) and IWC[*1], and organisms removed and dispersed into the sea area by IWC and which survived to reach sexual maturity [*2]

Unit: pieces/10,000 mm^2/year

Period	Standard case (Calculation case 1)	IWC implemented (Calculation case 6)	
	Current technique (self-polishing antifouling paint with 3-year effective performance)	The number of sexually mature organisms attached to hull skin after IWC implementation	The number of organisms that were removed and dispersed into the sea area by IWC and which survived and reached sexual maturity (not collected with a net)
Year 0 to 1	0.3	0.3	0.0
Year 1 to 2	9.4	4.2	2.1
Year 2 to 3	50.3	9.1	41.4

The number of sexually mature individuals in country A is the same as that in country B.

*1: IWC is implemented at one-year intervals in a port of the country which the ship enters just under one year after leaving dock.

*2: total number of organisms per unit area per year

Table 6.2-19 Accumulated egg production by organisms that are attached to a ship processed with the current technique (self-polishing antifouling paint), organisms attached to the hull skin after IWC [*1], and organisms removed and dispersed into the sea area by IWC and which survived to reach sexual maturity

Unit: egg production/10,000 mm^2

After leaving dock (Period)	Standard case (Calculation case 1)	IWC implemented [*1] (Calculation case 6)		
	Current technique (self-polishing antifouling paint with 3-year effective performance)	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (a) + (b)
1 year	1.56×10^3	1.56×10^3	0.0	1.56×10^3
2 years	4.51×10^4	2.13×10^4	9.79×10^3	3.11×10^4
3 years	2.78×10^5	6.37×10^4	2.02×10^5	2.66×10^5

Accumulated egg production in country A is the same as that in country B.

*1: IWC is implemented at one-year intervals in a port of the country which the ship enters just under one year after leaving dock.

Table 6.2-20 The ratio of accumulated egg production in the test case (IWC implementation) to that in the standard case

Period after leaving dock (years)	Standard case (Calculation case 1)	IWC implemented (Calculation case 6)		
	Current technique (self-polishing antifouling paint) (with 3-year effective antifouling performance)	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (a) + (b)
1 year	1	1	0	1
2 years	1	0.473	0.217	0.690
3 years	1	0.228	0.724	0.953

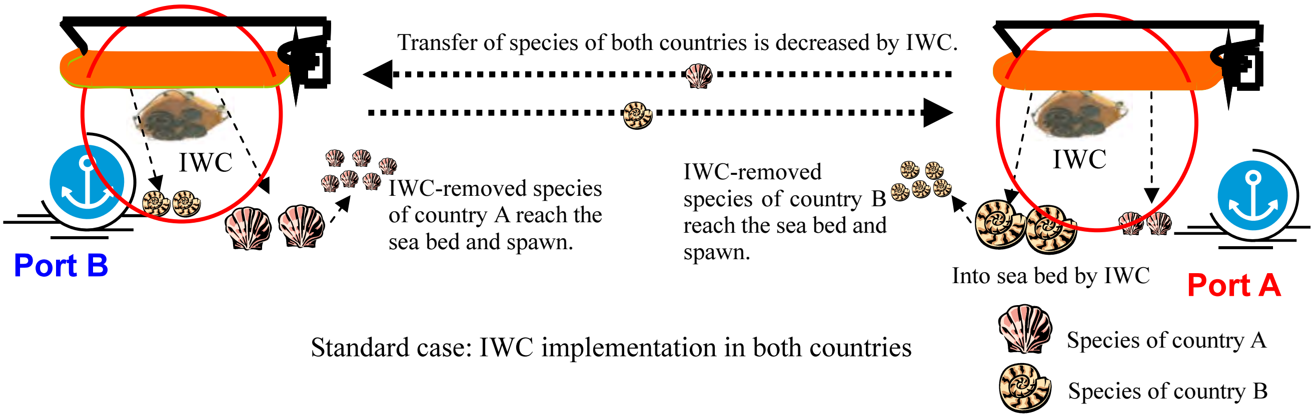
b) Evaluation of the difference in egg production between different countries in which IWC is implemented

IWC is generally implemented in a port in accordance with the rules of the two countries involved (just before the one-year or 6-month mark). However, in consideration of the ban imposed on IWC in some countries, for evaluation purposes it was assumed that IWC might be implemented in only one country (country A in the northern hemisphere in this survey).

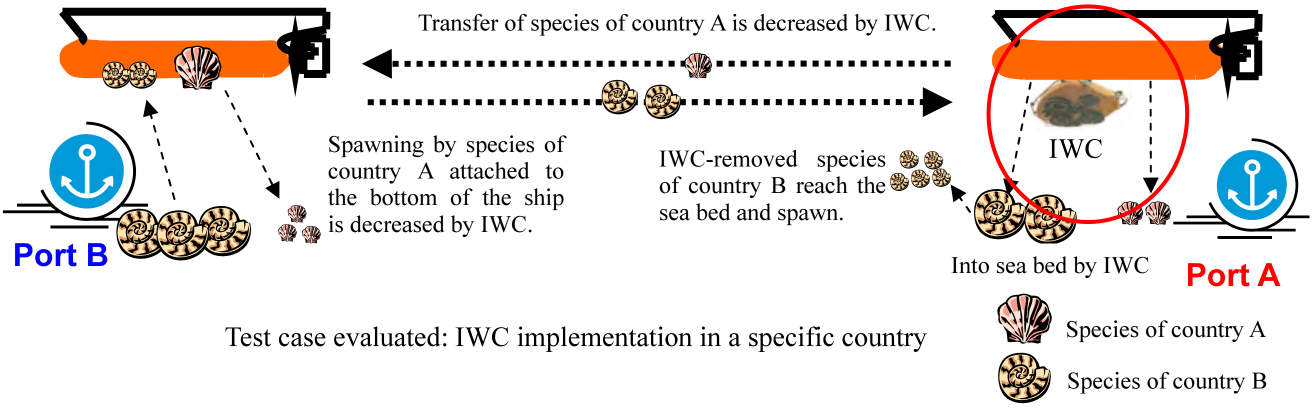
The case in which IWC was implemented in both countries was considered the standard case for evaluation purposes and compared with the test case in which IWC was implemented in only one country. In both cases, it was assumed that IWC-removed materials were not collected and all organisms in the removed materials were dispersed into sea areas. In both cases, the current technique (self-polishing antifouling paint with 3-year effective performance) was selected as the antifouling technique. The cases used for evaluation purposes are shown in Figure 6.2-4.

Table 6.2-21 Evaluation of the effect of IWC implementation on egg production

Objective of evaluation	Standard case (Calculation case 6)	Test case evaluated (Calculation case 7)
Difference between countries in which IWC is implemented	IWC implementation every year in 2 countries (removed materials are not collected).	IWC implementation at one-year intervals in a specific country (removed materials are not collected).



Standard case: IWC implementation in both countries



Test case evaluated: IWC implementation in a specific country

Figure 6.2-4 Changes in egg production in countries in which IWC is implemented

Table 6.2-22 shows the annually accumulated number of sexually mature organisms that have attached to hull skin after IWC implementation and reached sexual maturity, and the number of sexually mature organisms that have been removed and dispersed into the sea area by IWC. Table 6.2-23 shows the annually accumulated egg production from organisms that have attached to hull skin after IWC implementation and reached sexual maturity, from sexually mature organisms that have been dispersed into the sea area by IWC, and from organisms that have been dispersed into the sea area and reached sexual maturity there. The ratios of accumulated egg production in the test cases to that of the standard case are shown in Table 6.2-24.

Accumulated egg production in country A, i.e., total egg production by organisms that attached to hull skin after IWC implementation and by organisms that were removed and dispersed into the sea area by IWC, was estimated to be in the order of 10^3 pieces/10,000 mm^2 for one year after leaving a dock, 10^4 pieces/10,000 mm^2 for 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 for 3 years after leaving dock. Since IWC was only implemented in country A, the accumulated egg production in country A for 2 and 3 years after leaving dock was larger than that obtained in the standard case.

As shown by accumulated egg production in calculation cases 6 and 7 in Table 6.2-23, as a result of IWC implementation in only one of the two countries the 3-year accumulated egg production in the country where IWC was implemented (4.68×10^5 pieces) increased 1.76-fold compared with the 3-year accumulated egg production when IWC was implemented in both countries (2.66×10^5 pieces). In contrast, the 3-year accumulated egg production in a country where IWC was not implemented (6.37×10^4 pieces; (c) in Table 6.2-23) decreased 0.24-fold compared with the 3-year accumulated egg production when IWC was implemented in both countries (2.66×10^5 pieces). Furthermore, as shown by the result in calculation case 7, the 3-year accumulated egg production in a country where IWC was implemented (4.68×10^5 pieces: (c) + (d) in Table 6.2-23) increased 7.35-fold compared with the 3-year accumulated egg production in a country where IWC was not implemented (6.37×10^4 pieces; (c) in Table 6.2-23).

The above estimation was based on the assumption that ships were involved in a round trip between the 2 countries. However, in a trip involving 3 or more countries, the dose in a country where IWC was not implemented decreased even further, leading to a greater difference in dose between countries where IWC was implemented and those where it was not. This result indicates that the risk of organism transfer in a country where IWC is implemented increases while the risk in a country where IWC is banned decreases, even though IWC may have been implemented in order to reduce the risk of transfer of alien marine species. This sort of result is obviously unfair to some countries. Therefore, if IWC is adopted as an international measure, IWC should be implemented in all countries in order to decrease the risk of organism transfer all around the world.

Table 6.2-22 The annually accumulated number of sexually mature organisms that are attached to hull skin after IWC and spawn *1, and organisms that are removed and dispersed into the sea area (country A in the northern hemisphere) by IWC and have survived and reached sexual maturity in 2 test cases: one involving IWC in both countries and one involving IWC in only one country (country A in the northern hemisphere)

Unit: pieces/10,000 mm^2/year

Period	Standard case: IWC implementation in two countries (Calculation case 6)		IWC implementation in only one country, in the northern hemisphere (Calculation case 7)	
	The number of organisms that attached to hull skin after IWC implementation and reached sexual maturity	The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	The number of organisms that attached to hull skin after IWC implementation and reached sexual maturity	The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)
Year 0 to 1	0.3	0.0	0.3	0,0
Year 1 to 2	4.2	2.1	4.2	4.2
Year 2 to 3	9.1	41.4	9.1	82.7

The data shown in the table express the number of organisms that are found in country B in the southern hemisphere, where IWC is not implemented, and transferred to country A as a dose.

*1: total number of organisms per unit area per year

Table 6.2-23 The annually accumulated egg production from organisms that have attached to hull skin after IWC and organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity in 2 cases: one involving IWC in both countries and one involving IWC in only one country (country A in the northern hemisphere)

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case: IWC implementation in two countries (Calculation case 6)			IWC implementation in only one country, in the northern hemisphere (Calculation case 7)		
	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (a) + (b)	(c) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(d) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (c) + (d)
1 year	1.56×10^{3}	0.0	1.56×10^{3}	1.56×10^{3}	0.0	1.56×10^{3}
2 years	2.13×10^{4}	9.79×10^{3}	3.11×10^{4}	2.13×10^{4}	1.96×10^{4}	4.09×10^{4}
3 years	6.37×10^{4}	2.02×10^{5}	2.66×10^{5}	6.37×10^{4}	4.04×10^{5}	4.68×10^{5}

The data shown in the table express the accumulated egg production by organisms found in country B, in the southern hemisphere, where IWC is not implemented and transferred to country A as a dose.

Table 6.2-24 The ratio of accumulated egg production in the test case (IWC in one country in the northern hemisphere) to that in the standard case

Period after leaving dock (years)	Standard case: IWC implementation in two countries (Calculation case 6)			IWC implementation in only one country, in the northern hemisphere (Calculation case 7)		
	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (a) + (b)	(c) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(d) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (c) + (d)
1 year	1	0	1	1	0	1
2 years	1	0.460	1.46	1	0.919	1.92
3 years	1	3.17	4.17	1	6.35	7.35

c) Evaluation of the effect of IWC interval on egg production

The effect of IWC at shorter (6-month) intervals was evaluated. The case in which IWC was implemented at one-year intervals was considered to be the standard case and compared with IWC implemented at 6-month intervals, for a ship simply shuttling between countries A and B and treated using IWC at a specified port at 6-month intervals. It was assumed that IWC-removed materials were not collected and that all organisms in the removed materials were dispersed into the sea areas and that the current technique (self-polishing antifouling paint with 3-year performance) was applied in both cases.

Table 6.2-25 Evaluation of the effect of IWC interval on egg production

Objective of evaluation	Standard case. (Case 6)	Test case evaluated. (Case 8)
Effect of the IWC interval	IWC implementation at one-year intervals (removed materials were not collected)	IWC implementation at 6-month intervals (removed materials were not collected)

Table 6.2-26 shows the annually accumulated number of sexually mature organisms that attached to hull skin after IWC implementation and reached sexual maturity, and the number of sexually mature organisms that were removed and dispersed into the sea area by IWC. Table 6.2-27 shows the ratios of annually accumulated egg production from organisms that attached to hull skin after IWC implementation and reached sexual maturity, from sexually mature organisms that were dispersed into the sea area by IWC, and from organisms that were dispersed into the sea area and reached sexual maturity. The ratios of accumulated egg production in the test cases to that in the standard case are shown in Table 6.2-28.

Accumulated egg production, i.e., total egg production from organisms that attached to hull skin after IWC implementation and from organisms that were removed and dispersed into the sea area by IWC, was estimated to be 0 for one year after leaving dock, in the order of 10^4 pieces/10,000 mm^2 for 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 for 3 years after leaving dock. Accumulated egg production when IWC was implemented at 6-month intervals was lower than that at one-year intervals until 2 years after leaving dock, and almost similar 3 years later. The 3-year accumulated egg production when IWC was implemented at 6-month intervals accounted for 91.3% of the total.

It should be noted that no sexually mature organism can be attached to the hull skin when IWC is implemented at 6-month intervals. In this case, egg production is carried out by organisms that have been removed and dispersed into the sea area. When IWC is implemented at 6-month intervals, organisms attached to hull skin are sexually immature and only reach sexual maturity and spawn in the sea area after they are removed and dispersed. In the estimation based on egg production by the organisms that were dispersed, the dose (3-year accumulated egg production) when IWC was implemented at 6-month intervals was 120% of the value obtained in the standard case.

Therefore, if IWC-removed materials are collected with a net of appropriate mesh size in order to reduce the dispersal of immature organisms, the dose can be significantly reduced when IWC is implemented at 6-month intervals. The calculation results for accumulated egg production after the collection of removed materials, as shown in the Data Section (Data-4), indicate that estimated egg production when removed materials are collected using a net of 10 mm mesh size is zero until 2 years after leaving dock and of the order of 10^5 pieces/10,000 mm^2 for 3 years after leaving dock. When using a net of 5 mm mesh size, the 3-year accumulated egg production is estimated to be of the order of 10^4 pieces/10,000 mm^2. This result suggests that if IWC is implemented at 6-month intervals and IWC-removed materials are collected using a net of 5 mm mesh size, the 3-year accumulated egg production can be decreased by at least 1 order or magnitude compared with 3-year accumulated egg production when IWC is only implemented at one-year intervals.

Table 6.2-26 The number of sexually mature organisms that attached to hull skin after IWC implementation at one-year or 6-month intervals[*1] and the number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity

Unit: pieces/10,000 mm^2/year

Period	Standard case: IWC implementation at one-year intervals (Case 6)		IWC implementation at 6-month intervals (Case 8)	
	The number of organisms that attached to hull skin after IWC implementation and reached sexual maturity	The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	The number of organisms that attached to hull skin after IWC implementation and reached sexual maturity	The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)
Year 0 to 1	0.3	0.0	0.0	0.0
Year 1 to 2	4.2	2.1	0.0	3.1
Year 2 to 3	9.1	41.4	0.0	49.0

The number of sexually mature individuals in country A is the same as that in country B.

*1: total number of organisms per unit area per year

Table 6.2-27 Accumulated egg production by sexually mature organisms that attached to hull skin after IWC implementation at one-year or 6-month intervals and organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case: IWC implementation at one-year intervals (Case 6)			IWC implementation at 6-month intervals (Case 8)		
	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (a) + (b)	(c) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(d) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (c) + (d)
1 year	1.56×10^3	0.0	1.56×10^3	0.0	0.0	0.0
2 years	2.13×10^4	9.79×10^3	3.13×10^4	0.0	1.45×10^4	1.46×10^4
3 years	6.37×10^4	2.02×10^5	2.66×10^5	0.0	2.43×10^5	2.43×10^5

Accumulated egg production in country A is the same as that in country B.

Table 6.2-28 The ratio of accumulated egg production in the test case (IWC at 6-month intervals) to that in the standard case

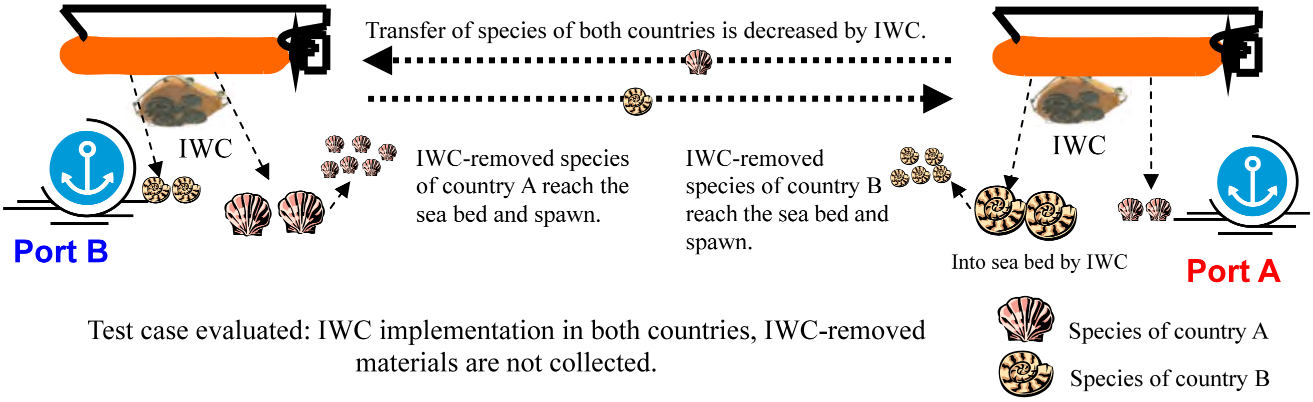
Period after leaving dock (years)	Standard case: IWC implementation at one-year intervals (Case 6)			IWC implementation at 6-month intervals (Case 8)		
	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (a) + (b)	(c) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(d) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)	Total (c) + (d)
1 year	1	0	1	0	0	0
2 years	1	0.460	1.46	0	0.683	0.683
3 years	1	3.17	4.17	0	3.81	3.81

d) Assessment of collection of IWC-removed materials

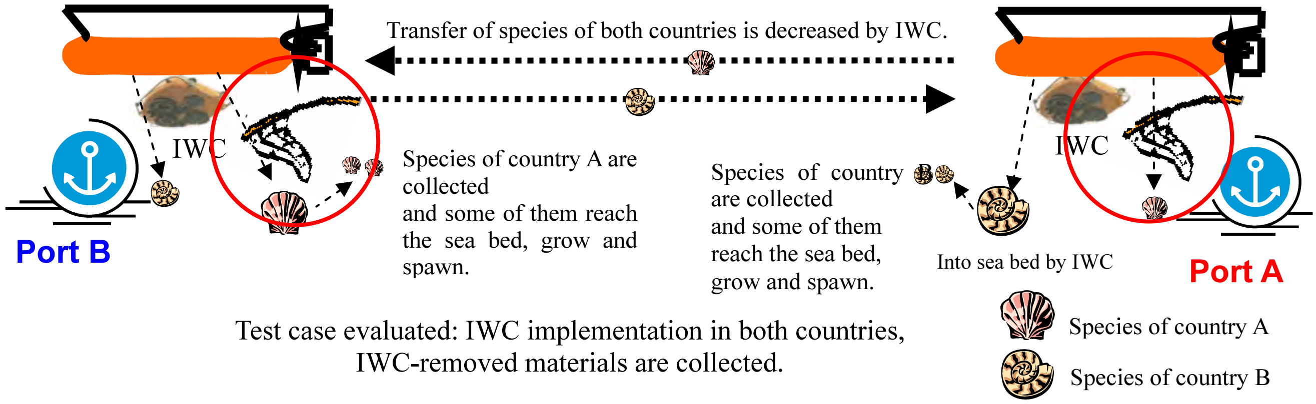
In this survey, it was assumed that IWC-removed materials 0.3 mm or more in size can be collected by an improved collecting device (see Section 4.3.2 i). In this section, the extent to which the risk of organism transfer could be reduced by collecting IWC-removed materials was estimated. The case in which IWC-removed materials were not collected was considered to be the standard case and compared with test cases in which IWC-removed materials were collected using a net of 10, 5 or 0.5 mm mesh size (see Figure 6.2-5).

Table 6.2-29 Effect of the collection of IWC-removed materials on egg production

Objective of evaluation	Standard case (Case 6)	Test case evaluated (Case 9)
Effect of collection of IWC-removed materials	IWC implementation at one-year intervals (removed materials are not collected)	IWC implementation at one-year intervals (collected with a net of 10, 5 or 0.5 mm mesh size)



Test case evaluated: IWC implementation in both countries, IWC-removed materials are not collected.



Test case evaluated: IWC implementation in both countries, IWC-removed materials are collected.

Figure 6.2-5 Effect of the collection of IWC-removed materials on egg production

Table 6.2-30 shows the annually accumulated number of sexually mature organisms that attached to the hull skin after IWC implementation and reached sexual maturity, and the number of sexually mature organisms that were removed and dispersed into the sea area by IWC. Table 6.2-31 shows the ratios of annually accumulated egg production by organisms that attached to the hull skin after IWC implementation and reached sexual maturity with that of sexually mature organisms that were dispersed into the sea area by IWC and organisms that were dispersed into the sea area and reached sexual maturity there. The ratios of accumulated egg production in the test cases to that in the standard case are shown in Table 6.2-32.

When IWC-removed materials were collected, no egg production occurred from organisms that were dispersed into the sea area until 2 years after leaving dock, regardless of the mesh size of the collection net. Consequently, egg production within 2 years of leaving dock was carried out solely by organisms that attached to hull skin after IWC implementation. However, 3 years after leaving dock, egg production by organisms that were dispersed into the sea area was added and the accumulated egg production was estimated to be of the order of 10^5 pieces/10,000 mm^2 with a 10 mm mesh size and 10^4 pieces/10,000 mm^2 with a 5 and 0.5 mm mesh size, showing a rapid increase.

The dose (3-year accumulated egg production) when IWC-removed materials were collected decreased to 41.3%, 34.5% and 24.0% at 10, 5 and 0.5 mm mesh sizes, respectively. Accumulated egg production solely from organisms that were dispersed into sea areas decreased to 22.8%, 13.9% and 0% of the standard value at 10, 5 and 0.5 mm mesh sizes, respectively. Thus, the collection of removed materials was still extremely effective even with a net with a relatively large mesh size. Collection with a net of even smaller mesh size could be expected to reduce the risk of transferring organisms smaller than the subject species examined in this survey.

As described in a), the evaluation of the effectiveness of IWC implementation on egg production, IWC-removed materials should always be collected in the future. The collection of materials removed by IWC will significantly reduce the risk of organism transfer all over the world. The above results suggest that the subject species examined in this survey can be completely and effectively collected with a net with a mesh size of 0.5 mm. However, all species can be collected with a net with a mesh size smaller than 0.5 mm.

As described in b), the mesh size used for IWC should be subject to international standardization in order to avoid any confusion over IWC implementation.

Table 6.2-30 The annually accumulated number of organisms that attached and reached sexual maturity after IWC implementation at one-year intervals and organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity, compared with the number of organisms that survived and reached sexual maturity when IWC-removed materials were collected with a net of 10, 5 and 0.5 mm mesh size[*1]

Unit: pieces/10,000 mm^2/year

Period	Standard case (Case 6) IWC implementation at one-year intervals without the collection of removed materials		IWC implementation at one-year intervals with the collection of removed materials (Case 9) (collected with net of 10, 5 or 0.5 mm mesh)		
	The number of organisms that attached to hull skin after IWC implementation and reached sexual maturity	The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity		
			Materials 10 mm or larger collected.	Materials 5mm or larger collected.	Materials 0.5 mm or larger collected.
Year 0 to 1	0.3	0.0	0.0	0.0	0.0
Year 1 to 2	4.2	2.1	0.0	0.0	0.0
Year 2 to 3	9,1	41.4	9.9	6.0	0.0

Accumulated egg production in country A is the same as that in country B.

*1: total number of organisms per unit area per year

Table 6.2-31 The annually accumulated egg production by organisms that attached and reached sexual maturity after IWC implementation at one-year intervals and organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity, compared with the number of organisms that survived and reached sexual maturity when IWC-removed materials were collected with a net of 10, 5 and 0.5 mm mesh size

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case (Case 6) IWC implementation at one-year intervals without the collection of removed materials			IWC implementation at one-year intervals with collection of removed materials (Case 9) (collected with net of 10, 5 or 0.5 mm mesh size)					
				Materials <10 mm not collected		Materials <5 mm not collected		Materials <0.5 mm not collected	
	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (b)	(c) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (c)	(d) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (d)	(e) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (e)
1 year	1.56×10^3	0.0	1.56×10^3	0.0	1.56×10^3	0.0	1.56×10^3	0.0	1.56×10^3
2 years	2.13×10^4	9.79×10^3	3.11×10^4	0.0	2.13×10^4	0.0	2.13×10^4	0.0	2.13×10^4
3 years	6.37×10^4	2.02×10^5	2.66×10^5	4.60×10^4	1.10×10^5	2.80×10^4	9.17×10^4	0.0	6.37×10^4

Accumulated egg production in country A is the same as that in country B.

Table 6.2-32 The ratios of accumulated egg production in the test cases (IWC implementation) to that in the standard case

Period after leaving dock (years)	Standard case (Case 6) IWC implementation at one-year intervals without collection of removed materials			IWC implementation at one-year intervals with collection of removed materials (Case 9) (collected with a net of 10, 5 or 0.5 mm mesh size)					
				Materials <10 mm not collected		Materials <5 mm not collected		Materials <0.5 mm not collected	
	(a) Egg production by organisms that attached to hull skin after IWC implementation and reached sexual maturity	(b) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (b)	(c) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (c)	(d) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (d)	(e) Egg production by organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity	Total (a) + (e)
1 year	1	0	1	0	1	0	1	0	1
2 years	1	0.460	1.46	0	1	0	1	0	1
3 years	1	3.17	4.17	0.722	1.72	0.440	1.44	0	1

6.2.3 Effect of shipping schedules (assessment of offshore waiting)

In Australian ports, colliers and iron ore carriers often wait offshore for a long period of time due to loading requirements. Offshore waiting was originally an issue related to shipping schedules. However, since offshore waiting could also increase the number of biofouling organisms, egg production was assessed along with the implementation of IWC after offshore waiting.

(1) Assessment of offshore waiting

The case of a ship processed with the current technique (self-polishing antifouling paint with 3-year performance) and then simply shuttling between countries A and B was adopted as the standard case and compared to the test case of a ship waiting offshore for 14 days while waiting to load/unload in country B (Table 6.2-33). The effects of offshore waiting on biofouling and egg production are shown in Figure 6.2-6. Offshore waiting increased both the number of organisms that attached to the hull skin at sea and the egg production by sexually mature organisms that attached themselves in another country (country A), resulting in increased egg production by alien species in both countries.

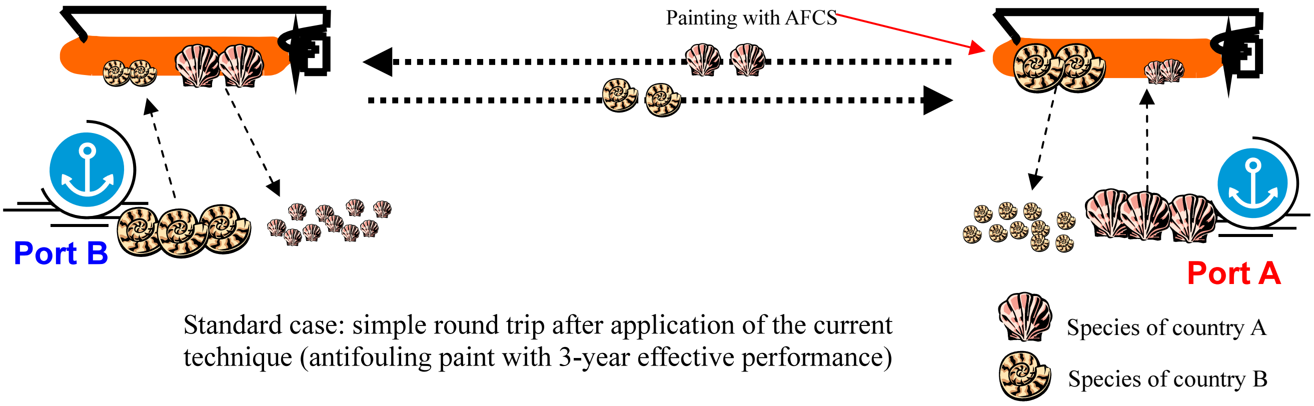
Table 6.2-33 Evaluation of the effect of offshore waiting on egg production

Objective of evaluation	Standard case (Calculation case 1)	Test case evaluated (Calculation case 12)
Assessment of offshore waiting	Application of the current technique (self-polishing antifouling paint) and simple shuttling between countries A and B	Application of the current technique (self-polishing antifouling paint) and offshore waiting in country B for 14 days while waiting to load/unload

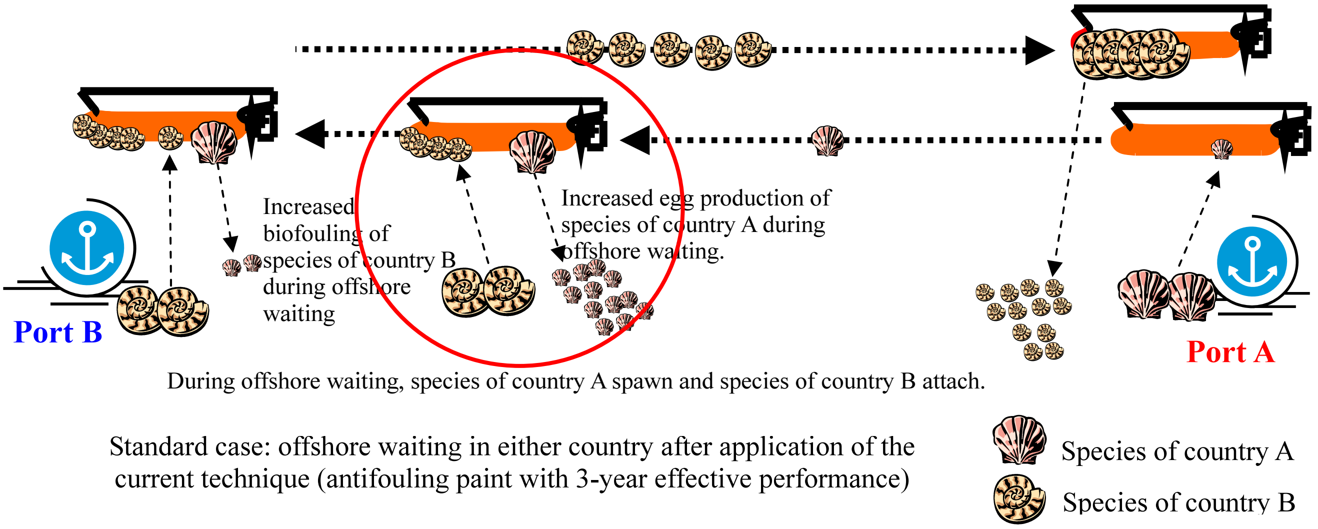
The annually accumulated number of sexually mature organisms that are attached to the hull outer skin and spawn is shown in Table 6.2-34. The annually accumulated egg production by sexually mature organisms is shown in Table 6.2-35. The ratios of accumulated egg production in the test cases compared to that in the standard case are shown in Table 6.2-36. Accumulated egg production was calculated for 3 years from leaving dock until returning to dock.

When a ship waits offshore in country B, the accumulated egg production in country B from organisms attached in country A and that in country A from organisms attached in country B was estimated to be in the order of 10^3 pieces/10,000 mm^2 for 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 for 3 years after leaving dock.

The dose in country B with offshore waiting increased to 311.2% of the standard value and the dose in country A, without offshore waiting, increased to 297.1%. Consequently, offshore waiting was a disadvantage to both countries A and B.



Standard case: simple round trip after application of the current technique (antifouling paint with 3-year effective performance)



Standard case: offshore waiting in either country after application of the current technique (antifouling paint with 3-year effective performance)

Figure 6.2-6 Effect of offshore waiting on egg production

Table 6.2-34 Annually accumulated number of sexually mature organisms that attach to hull skin and spawn on a ship processed with the current technique (self-polishing antifouling paint) and shuttling between two countries, compared with a ship waiting offshore in country B[*1]

Unit: pieces/10,000 mm^2/year

Period	Standard case: simple shuttle between countries A and B by a ship processed with the current antifouling paint (Calculation case 1)	Offshore waiting in country B (Calculation case 12)	
		The number of sexually mature organisms that attach in country A and spawn in country B	The number of sexually mature organisms that attach in country B and spawn in country A
Year 0 to 1	0.3	1.1	0.9
Year 1 to 2	9.4	27.2	28.3
Year 2 to 3	50.3	158.3	149.0

*1: total number of organisms per unit area per year

Table 6.2-35 Egg production by sexually mature organisms that attach to hull skin and spawn on a ship processed with the current technique (self-polishing antifouling paint) and shuttling between two countries, compared with a ship waiting offshore in country B

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case (Calculation case 1)	Offshore waiting in country B (Calculation case 12)	
	Current basic antifouling paint (3-year effective antifouling performance)	Accumulated egg production in country B by organisms that attached in country A	Accumulated egg production in country A by organisms that attached in country B
1 year	1.56×10^3	5.21×10^3	4.12×10^3
2 years	4.51×10^4	1.31×10^5	1.36×10^5
3 years	2.79×10^5	8.68×10^5	8.29×10^5

Table 6.2-36 Ratio of accumulated egg production in the test case (offshore waiting in country B) compared to that found in a ship shuttling between two countries

Period after leaving dock (years)	Standard case (Calculation case 1)	Offshore waiting in country B (Calculation case 12)	
	Current basic antifouling paint (3-year effective antifouling performance)	Accumulated egg production in country B by organisms that attached in country A	Accumulated egg production in country A by organisms that attached in country B
1 year	1	3.35	2.65
2 years	1	2.92	3.01
3 years	1	3.11	2.97

(2) Evaluation of IWC in the case of offshore waiting

The effect of IWC in the case of offshore waiting was evaluated. The case involving a ship processed with the current technique (self-polishing antifouling paint with 3-year performance) and simply shuttling between countries A and B was adopted as the standard case and compared with a ship waiting offshore for 14 days while waiting to load/unload in country B with IWC implemented at one-year intervals in country A, a country without offshore waiting. The changes in biofouling and egg production due to offshore waiting and IWC implementation are shown in Figure 6.2-7. If IWC is implemented in a country without offshore waiting, many organisms that attached to hull skin in a country with offshore waiting are transferred to the sea area of the country in which IWC is implemented, resulting in increased egg production in that country.

Table 6.2-37 Evaluation of IWC in the case of offshore waiting

Objective of evaluation	Standard case (Calculation case 12)	Test case evaluated (Calculation case 13)
Effect of IWC in the case of offshore waiting	Application of the current technique (self-polishing antifouling paint) and offshore waiting in country B	Combination of antifouling paint specified in the left-hand column and IWC (removed materials are not collected).

The annually accumulated number of sexually mature organisms that are attached to the outer hull skin and spawn is shown in Table 6.2-38. The annually accumulated egg production from these sexually mature organisms is shown in Table 6.2-39 The ratio of accumulated egg production in the test cases to that in the standard case is shown in Table 6.2-40. The accumulated egg production was calculated for 3 years from leaving dock until returning to dock.

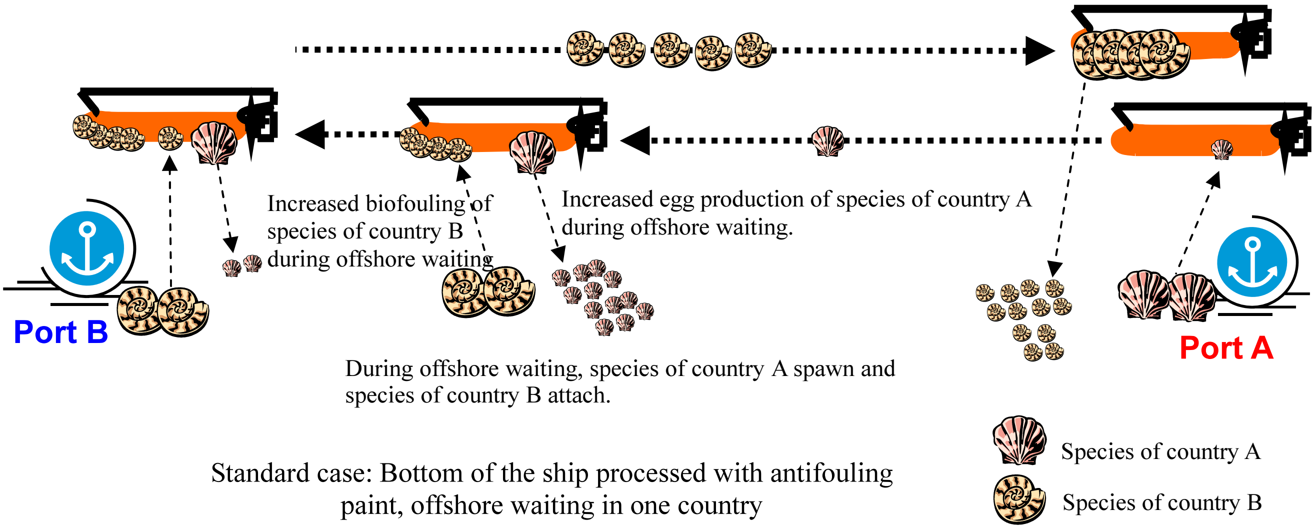
The evaluation results for offshore waiting and IWC implementation in country B are summarized below.

In the standard case without IWC, egg production by alien species in countries A and B was almost equal. Egg production was estimated to be in the order of 10^3 pieces/10,000 mm^2 for one year after leaving dock, 10^5 pieces/10,000 mm^2 for 2 years after leaving dock, and 10^5 pieces/10,000 mm^2 for 3 years after leaving dock.

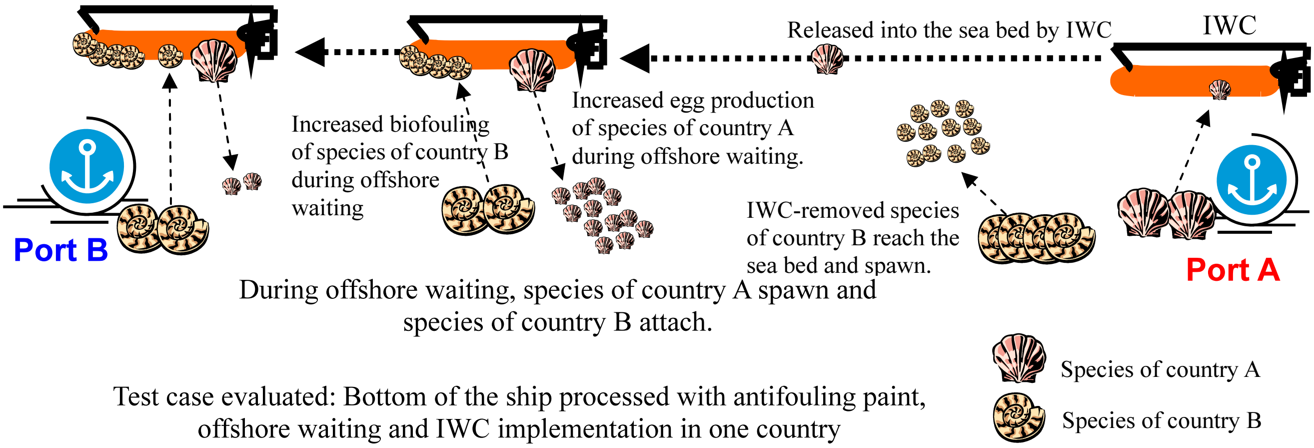
In contrast, in the case of offshore waiting in country B and IWC implementation in country A, the dose in country B decreased to 40.2% of the standard value and the dose in country A increased to 127.3%. The increased dose in country A was caused by species from country B that attached during offshore waiting and were dispersed into the sea area by IWC implementation in country A.

When the combination of offshore waiting and IWC was compared to the test case without offshore waiting (using case 1 as the standard), the dose (3-year accumulated egg production) in the country with offshore waiting was 125.1% of the standard value and that in the country without offshore waiting was 378.2%, i.e., the dose increased in both countries compared to the test case without offshore waiting (case 1). This is a significant effect which is too big to ignore. In such conditions, the collection of IWC-removed materials is an effective measure to decrease the dose of a country without offshore waiting.

Offshore waiting should be recognized as a factor that can increase egg production by alien species, not only in a country where ships wait offshore but also in other countries as well, and it is important for those shipping routes with a high frequency of offshore waiting to take measures to reduce egg production in both countries and to establish international agreements and adopt standardized procedures.



Standard case: Bottom of the ship processed with antifouling paint, offshore waiting in one country



Test case evaluated: Bottom of the ship processed with antifouling paint, offshore waiting and IWC implementation in one country

Figure 6.2-7 Changes in biofouling and egg production in the case of IWC implementation in a country without offshore waiting

Table 6.2-38 Number of sexually mature organisms that attached to hull skin after the current technique (self-polishing antifouling paint) and IWC, and organisms that were removed and dispersed into the sea area by IWC and grew[*1]

Unit: pieces/10,000 mm^2/year

Period	Standard case: current technique (antifouling paint with 3-year performance) + offshore waiting in country B (Calculation case 12)		Offshore waiting in country B + IWC[*2] (not collected with a net). (Calculation case 13)			
	The number of sexually mature organisms that attach to hull skin in country A and spawn in country B (Annual total of sexually mature organisms)	The number of sexually mature organisms that attach to hull skin in country B and spawn in country A (Annual total of organisms)	The number of organisms that attach to hull skin and reach sexual maturity after IWC implementation (Annual total of organisms)		The number of sexually mature organisms that were removed and dispersed into the sea area by IWC and organisms that reach sexual maturity after dispersal	
			Attachment in country A and spawning in country B	Attachment in country B and spawning in country A	Attachment in country A and spawning in country B	Attachment in country B and spawning in country A
Year 0 to 1	1.1	0.9	1.1	0.9	0.0	0.0
Year 1 to 2	27.2	28.3	13.3	13.5	0.9	7.3
Year 2 to 3	158.3	149.0	34.7	29.4	25.0	175.3

*1: total number of organisms per unit area per year

*2: IWC is implemented at one-year intervals in a port of the country which the ship enters just under one year after leaving dock.

Table 6.2-39 Accumulated egg production by sexually mature organisms that attached to hull skin after the current technique (self-polishing antifouling paint) and IWC[*1] and by sexually mature organisms that were removed and dispersed by IWC

Unit: egg production/10,000 mm^2

Period after leaving dock (years)	Standard case: current technique (antifouling paint with 3-year performance) + offshore waiting in country B (Calculation case 12)		Offshore waiting in country B + IWC (not collected with a net). (Calculation case 13)					
	Accumulated egg production in country B by organisms that attached in country A	Accumulated egg production in country A by organisms that attached in country B	Accumulated egg production by organisms that attached to hull skin after IWC implementation		The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)		Total [*2]	
			(a) Attachment in country A and spawning in country B	(b) Attachment in country B and spawning in country A	(c) Attachment in country A and spawning in country B	(d) Attachment in country B and spawning in country A	(a) + (c) Attachment in country A and spawning in country B	(b) + (d) Attachment in country B and spawning in country A
1 year	5.21×10^3	4.12×10^3	5.21×10^3	4.12×10^3	0.0	0.0	5.21×10^3	4.12×10^3
2 years	1.32×10^4	1.36×10^5	6.68×10^4	6.71×10^4	4.23×10^3	3.38×10^4	7.11×10^4	1.01×10^5
3 years	8.68×10^5	8.29×10^5	2.28×10^5	2.04×10^5	1.21×10^5	8.51×10^5	3.49×10^5	1.05×10^6

*1: IWC implementation at one-year intervals in a port of a country which the ship enters just under one year after leaving dock.

*2: Test subject compared with the standard case

Table 6.2-40 Ratio of accumulated egg production in the test cases (offshore waiting and IWC implementation) to that of offshore waiting in country B

Period after leaving dock (years)	Standard case: current technique (antifouling paint with 3-year performance) + offshore waiting in country B (Calculation case 12)		Offshore waiting in country B + IWC (not collected with a net). (Calculation case 13)					
	Accumulated egg production in country B by organisms that attached in country A	Accumulated egg production in country A by organisms that attached in country B	Accumulated egg production by organisms that attached to hull skin after IWC implementation		The number of organisms that were removed and dispersed into the sea area by IWC and survived and reached sexual maturity (not collected with a net)		Total [*1]	
			(a) Attachment in country A and spawning in country B	(b) Attachment in country B and spawning in country A	(c) Attachment in country A and spawning in country B	(d) Attachment in country B and spawning in country A	(a) + (c) Attachment in country A and spawning in country B	(b) + (d) Attachment in country B and spawning in country A
1 year	1	0.791	1	0.791	0	0	1	0.791
2 years	1	1.03	0.507	0.509	0.0321	0.257	0.539	0.766
3 years	1	0.954	0.263	0.235	0.139	0.980	0.402	1.21

*1: Test subject compared with the standard case

6.3 Summary of risk assessment for species transfer associated with application techniques

In the above chapters, various models were developed to estimate the risk of species transfer (based on egg production) and to evaluate antifouling techniques and removal techniques targeting biofouling organisms. Calculation results were used to estimate the changes in dose when each technique was applied in order to evaluate their efficacy. The evaluation results for each of these techniques are summarized in Table 6.3-1**.** An evaluation of the current techniques employed is also included.

Table 6.3-1 Evaluation of new and improved techniques and the influence of offshore waiting (regarded as effective when the value obtained is less than the standard value)

Item used for evaluation		Evaluation standard (100%)	Conditions used to evaluate the future technique	Effectiveness (%) of the future technique
antifouling paint	Evaluation of the current antifouling paint	Calculation case 1. Self-polishing antifouling paint with 3-year effective antifouling performance	Calculation cases 1, 2 and 3. Average effect when self-polishing antifouling paints with 1- to 3-year effective antifouling performance are mixed	164.4
	Effect of high-performance antifouling paint		Calculation case 4. (1) antifouling paint with 5-year effective antifouling performance and no attachment for 30 days after leaving dock	20.7
			Calculation case 5. (2) antifouling paint with 5-year effective antifouling performance and no attachment for 90 days after leaving dock	18.3
IWC	Effect of IWC implementation		Calculation case 6. IWC implementation at one-year intervals in the standard case (IWC-removed materials are not collected).	95.2
	Difference between countries in which IWC is implemented	Calculation case 6. IWC implementation at one-year intervals in two countries where IWC-removed materials are not collected.	Calculation case 7. IWC implementation at one-year intervals in a specific country in the standard case (IWC-removed materials are not collected).	Country in which IWC is implemented: 176.0 Country in which IWC is not implemented: 24.0
	Effect of IWC implementation interval		Calculation case 8. IWC implementation at 6-month intervals in the standard case. (IWC-removed materials are not collected).	91.3
	Effect of collection of IWC-removed materials		Calculation case 9. IWC implementation with collection of IWC-removed materials using a net of 10, 5 or 0.5 mm mesh size at one-year intervals in the standard case	10 mm: 41.3 5 mm: 34.5 0.5 mm: 24.0

Table 6.3-1 Evaluation of new and improved techniques and the influence of offshore waiting (regarded as effective when the value obtained is less than the standard value)

Item used for evaluation		Evaluation standard (100%)	Conditions used to evaluate the future technique	Effectiveness (%) of the future technique
Seawater electrolysis system	Effect of seawater electrolysis system	Calculation case 1' Self-polishing antifouling paint with 3-year effective antifouling performance and the initial falling rate set to 10% (50% in case 1) in consideration of the slow flow rate.	Calculation case 10. Addition of a seawater electrolysis system (a MGPS technique) in the standard case	94.6
	Effect of a combination of the seawater electrolysis system and IWC		Calculation case 11. Addition of a seawater electrolysis system and IWC (removed materials are not collected) in the standard case	91.0
Offshore waiting	Assessment of offshore waiting	Calculation case 1. Application of self-polishing antifouling paint with 3-year effective antifouling performance and simple shuttling between countries A and B (100%: the conditions of nations of original condition of countries with and without offshore waiting)	Calculation case 12. Offshore waiting in country B for a ship processed with self-polishing antifouling paint with 3-year effective antifouling performance	Country with offshore waiting: 311.2 Country without offshore waiting: 297.1
	Effect of IWC implementation on a ship waiting offshore.	Calculation case 12. Application of self-polishing antifouling paint with 3-year effective antifouling performance and offshore waiting in country B (100%: the conditions of nations of original condition of countries with and without offshore waiting)	Calculation case 13. IWC implementation (removed materials are not collected) in the standard case (offshore waiting in country B)	Country with offshore waiting: 40.2 Country without offshore waiting: 127.3 (Country in which IWC is implemented)

6.3.1 Anti-fouling system (AFS)

(1) Evaluation of antifouling paint used in AFCS as antifouling treatment

a) Evaluation of the current antifouling paint

- Self-polishing antifouling paint is currently a very popular technique. The performance of the current self-polishing antifouling paint is usually specified as being 3- or 5-year affective (it should be noted, however, that performance has not been assessed in standardized studies). Therefore, ships are scheduled to enter dock for cleaning on the basis of this expiration period and the corresponding interim inspection period. Most ships currently enter dock at 2.5-year intervals and cleaning of the hull surface is performed on almost all ships for antifouling purposes. Therefore, in practice, the effective period of antifouling can be considered to be less than 3 years, i.e., 2.5 years or less.

- The estimation results obtained in this survey show that the average dose (3-year accumulated egg production) when ships processed with antifouling paint with 1- to 3-year effective antifouling performance are evenly mixed increases to 164.4% of the value obtained in the standard case used for comparison (6.2.1(1)a)). Consequently, the relative invasion risk (dose) can be decreased by a ratio of 1/1.6 if the antifouling paint used on all ships at sea has a 3-year effective antifouling performance.

b) Evaluation of the future antifouling paint

- If the period of antifouling performance is extended to 5 years, the dose (3-year accumulated egg production) associated with no biofouling for 30 and 90 days is reduced to 20.7% and 18.3%, respectively, compared to the value obtained in the standard case using 3-year effective antifouling (6.2.1(1)b)).
- These estimation results suggest that any improvement in self-polishing antifouling paint contributes to a reduction in accumulated egg production by biofouling organisms (6.2.1(1)b)).

(2) Evaluation of the seawater electrolysis system in MGPSs as antifouling treatment

a) Evaluation of the current seawater electrolysis system

- The seawater electrolysis system, a MGPS, is currently used for the inner piping system of ships but not for the sea chest where biofouling is severe. As shown in Section 3.3.1 (2), no quantitative data are available for the antifouling effect of seawater electrolysis systems because no information is available on those cases when the seawater electrolysis system does not work. However, considering that many ships now use a seawater electrolysis system, this system can be expected to decrease the risk of organism transfer into the inner piping systems (3.3.1 (2)).

b) Evaluation of improved seawater electrolysis systems

- An evaluation was conducted on the technique used to inject chloride compounds from the seawater electrolysis system into the sea chest. When applying the seawater electrolysis system to a sea chest with severe biofouling, the concentration of chloride compound normally used to support the antifouling effect of antifouling paint had no effect. To use the seawater electrolysis system for biofouling control it is necessary to increase the concentration to 3 mg/L, the maximum allowable concentration, in consideration of the associated chemical environmental risks (6.2.1(2)a) i)).
- However, the ability of the seawater electrolysis system to reduce accumulated egg production (to 94.6%) in the sea chest, even though it is only relatively slight, suggests that the seawater electrolysis system is, nevertheless, a promising measure with the potential for further development. The seawater electrolysis system could become an effective measure if, in addition to the use of an appropriate concentration of chloride compound, a technique can also be developed to distribute chloride all over the wall of the sea chest and to continuously or intermittently inject the compound while the ship is still in harbor (6.2.1(2)a) i)).
- A combination of the seawater electrolysis system (a MGPS) and IWC is estimated to be able to reduce the dose (3-year accumulated egg production) to 91% of the value obtained in the standard case without IWC, even if IWC-removed materials are not collected. Although there is currently no decisive measure for use on the sea chest, IWC is an effective measure for controlling biofouling and its efficacy could be expected

to increase further when used in this role if IWC-removed materials are collected (6.2.1(2)a)Done by T ii)).

6.3.2 Removal technique for biofouling organisms

(1) Evaluation of the current In-Water Cleaning (IWC) system

- The current IWC system is generally used to reduce any increased friction and drag at sea caused by attached organisms on the outer hull and screw and to prevent any increase in fuel consumption due to biofouling (Section 4.3.1).
- Therefore, the current IWC system is used to completely remove all organisms firmly attached to the outer hull in order to increase the fuel efficiency of the ship (Section 4.3.1).
- In most (approximately 90%) of the facilities currently implementing IWC, soft nylon brushes are used and wire brushes are only applied to those areas where biofouling is severe (approximately 10%). (See section 4.3.1).
- The materials removed by IWC are usually not collected but released (dispersed) into sea areas. Only a very few facilities collect all the material removed using a net, and land and then treat it as industrial waste for disposal (Section 4.3.1).
- The level of current antifouling paint performance is less than that specified by the manufacturers. Therefore, any additional biofouling risk due to the use of IWC to remove attached materials is not estimated to be high. Consequently, it is not necessary to immediately ban IWC (6.2.2(2)a).

(2) Evaluation of improved IWC systems

- The dose (3-year accumulated egg production) in the case of a ship processed with IWC at one-year intervals was estimated to be 95.3% of the dose obtained in the standard case without IWC. Therefore, in order to use IWC effectively as part of a comprehensive antifouling control system, it is necessary to collect all IWC-removed materials (6.2.2(2)a)) and (6.2.2(2)d)).
- The effect of some countries banning IWC implementation was also investigated. The standard case used for estimation purposes assumed that IWC was implemented in both countries involved in a round trip between them. If IWC was always implemented in one of these countries but not always in the other, the dose (3-year accumulated egg production) in the country without IWC implementation decreased to 24.0% of the standard value while the dose in the country with IWC implementation increased to 176.0%. This large IWC-induced difference in dose can be considered significant (6.2.2(2)b)).
- In the test case examined where the IWC interval was reduced to 6 months, egg production by organisms attached to hull plating was zero. In the estimation carried out for total egg production by organisms attached to hull plating and by organisms that were removed and dispersed into the sea area by IWC, the dose (3-year accumulated egg production) was reduced to 91.3% of the standard value by shortening the IWC interval to 6 months. However, based on the amount of egg production by organisms that were removed and dispersed into the sea area by IWC, the dose was increased to 120% compared with the dose obtained in the standard case. It is, therefore, necessary to implement specific measures to ensure that organisms removed and dispersed into the sea area by IWC are collected in some manner (6.2.2(2)c)).
- The effect of the collection of IWC-removed materials on the dose was also estimated. The dose (3-year accumulated egg production) when IWC-removed materials were collected was reduced to 41.3%, 34.5%, and 24.0% of the standard value at 10, 5 and 0.5 mm mesh sizes, respectively. In terms of the egg production by those organisms that were removed and dispersed into the sea area by IWC, the dose (3-year accumulated egg production) when IWC-removed materials were collected was reduced to 22.8%, 13.9%

and 0% of the standard value at 10, 5 and 0.5 mm mesh sizes, respectively. Therefore, the collection of IWC-removed materials can be extremely effective (6.2.2(2)d)).

6.3.3 Effect on shipping schedules (assessment of offshore waiting)

As shown in Australia, colliers and iron ore carriers often wait offshore for a long time due to loading requirements. Therefore, the influence of offshore waiting was also assessed in terms of egg production. Since offshore waiting is related to shipping schedules, which are neither fixed nor constant, a standard case was adopted in which a ship simply shuttles back and forth between countries A and B and waits offshore upon arrival.

- Offshore waiting for 14 days while loading/unloading increases the dose (3-year accumulated egg production) both in those sea areas where the ship waits offshore and those where it does not. According to the model, the dose in a country with offshore waiting was 311.2% of the standard value and that in a country without offshore waiting was 297.1%, showing that there was an increase in the number of organisms becoming attached during offshore waiting in both countries (6.2.3(1)).
- When IWC was implemented in a country with offshore waiting, the dose (3-year accumulated egg production) increased to 40.2% of the standard value in the country with offshore waiting and to 127.1% in the country without offshore waiting. When these values were compared to the test case examined without offshore waiting (using calculation case 1 as the standard), the dose (3-year accumulated egg production) in the country with offshore waiting was 125.1% of the standard value and that in a country without offshore waiting was 378.2%, i.e., the dose increased in both countries compared to the case without offshore waiting (calculation case 1), producing a significant difference that is too big to ignore. In such conditions, the collection of IWC-removed materials is an effective measure to decrease the dose that ships are exposed to in any country without offshore waiting (6.2.3(2)).
- Offshore waiting should be recognized as having the potential to increase egg production by species, not only in any country where ships wait offshore but also in other countries, and it is important that shipping routes with a high frequency of offshore waiting take measures to reduce egg production and that all countries involved reach an agreement (6.2.3(2)).
- Therefore, in addition to further improvements in antifouling paint performance, appropriate shipping arrangements that take into consideration the risk of species transfer (including the minimization of offshore waiting) are required in order to establish an effective means of comprehensive control. Thus, it is important for all the IMO member nations to recognize the increased risks of species transfer associated with offshore waiting.

7. Comprehensive control system for biofouling species and its operation

7.0.1 In this chapter, based on the above results until Chapter 6, a comprehensive control and operation system for biofouling species is proposed, and the performance and operation standards for the devices and treatments required are analyzed and details of the system are summarized.

7.0.2 Chemical environmental risks and the transfer (amount) of species transferring, as described in Chapters 1 to 6, are basically interrelated. For example, if the antifouling effect of self-polishing AFCS on organisms increases, the chemical risk to the surrounding environment simultaneously increases. When developing a comprehensive antifouling control system, based on the results of this survey, it is important to select and combine valid and feasible treatments and operate them in consideration of both the risks of organism invasion and the associated chemical environmental risks.

7.0.3 Many cases of economic damage caused by biofouling species and cases of damaged ecosystems disturbed by alien species have recently been reported, although the damage to human health is not yet clear. There is much information available in Japan, also. Taking all this into consideration, a comprehensive biofouling control system should be established as soon as possible in order to facilitate the adoption of global countermeasures. In addition, the above system must be acceptable to the shipping industry. To actually operate a biofouling control system effectively within a framework of internationally unified standards, it is important to establish acceptable cost burdens for shipping agents. When standards specified by regulations are based on a different concept to that obtained from scientific evidence-based risk assessment, as shown in the Ballast Water Management Convention, unnecessary costs may impose a burden on the shipping business. In such a case, this burden can have a significant effect on the effectiveness of the regulations and, consequently, the initiation and content of the measures adopted may differ between different countries/regions, possibly resulting in increasing damage due to species invasion.

7.0.4 A comprehensive biofouling control system is proposed, based on the assumption that it will be operated in accordance with internationally unified standards at some point in the future. The adoption of enforceable regulations is expected because there have already been increasing reports of economic damage and ecocide caused by biofouling organisms. With regard to the risk of aquatic species transfer, the IMO is currently developing draft "Guidelines for the control and management of ships' biofouling to minimize the translocation of invasive aquatic species". While these guidelines are purely voluntary, if many cases of damage are reported to the IMO after the development of the draft guidelines, discussion on enforceable regulations may start within several years because voluntary-based guidelines, alone, will have no effect in reducing damage. In this chapter, a future comprehensive biofouling control system with enforceable regulations that could be introduced in the future is assumed and evaluated. The main aim of the proposed control system is to establish a comprehensive and reasonable framework based on treatment factors that reduce the risks of species transfer at a global level and have an acceptable level of chemical environmental risk. It is important that any such system established can be assessed and validated in accordance with internationally unified standards based on scientific evidence regarding the effects of various treatment factors on biofouling as well as their chemical risks and the associated risks of species transfer. In addition, the system should be feasible and acceptable to the shipping industry in order to promote its early implementation.

7.0.5 Taking all the above conditions into consideration, the basic concept proposed for the system consists of the following 3 items: [1] Performance standards, i.e., the necessary standards to ensure the required performance of treatment devices at acceptable levels of chemical environmental risk. The devices and treatments must meet the standards associated with their type approval. [2] Application standards, i.e., the necessary standards for the use of devices and treatments during construction and docking and on specific ship components. [3] Operation standards, i.e., the necessary standards to ensure that all devices and treatments meet the performance and application standards required to operate biofouling prevention and removal properly, and meet the necessary criteria to minimize both the risk of species transfer and associated chemical environmental risks. It is assumed that special sea areas will be designated in which different operation standards can be applied, compared to those in general sea areas, for the protection of rare species and for other reasons. However, the performance and application standards required for general and special sea areas will be common to both.

7.0.6 The proposed comprehensive biofouling control system consists of the following treatment factors for antifouling and the removal of organisms. [1] Antifouling treatment: AFCS products (antifouling paint developed and manufactured by paint companies and applied in shipyards) and the MGPS developed and produced by device manufacturers for the sea chest and inner piping use in the cooling water system and installed in shipyards), where MGPS is not limited to seawater electrolysis system. [2] Removal treatment for biofouling organisms: involving the removal of biofouling organisms using in-water cleaning (IWC) and other methods employed by diving companies while a ship is in harbour or at anchor.

7.0.7 These devices and treatments need to be able to prevent the attachment of and remove any large biofouling of organisms that can be visually detected (hereinafter referred to as macro-biofouling). The reason macro-biofouling has been selected is because, as described in "Chapter 6 Risks of species transfer", it is important for risk control purposes to distinguish whether or not sexually mature organisms that contribute to egg production (the major cause of species transfer) are attached to ships. From a control perspective, focusing on macro-biofouling is the most feasible means of visually detecting biofouling organisms. The assessment criteria for chemical environmental risks also need to address the combined toxicity of AFCS products including antifouling products and the MGPS device/treatment such as seawater electrolysis system, in order to confirm that chemical environmental risks are kept within allowable levels, similar to those of the ballast water management system.

7.0.8 The use of AFS to prevent or remove biofouling during construction and docking is specified in the application standards. It is expected that different antifouling products are applied to the outer hull skin and complex components such as the sea chest. The seawater electrolysis system, a leading MGPS can also be applied to the sea chest and inner piping, but not to the outer hull skin, at its current level of development. Considering its chemical risk, the seawater electrolysis system should not be used for hull skin.

7.0.9 The operation standards generally need to be able to maintain “clean ship” conditions of the hull surface, i.e. hull skin so that no macro-biofouling can be visually detected on the hull of the ship. Routine visual inspection of the outer hull plating is required to confirm the absence of macro-biofouling. If visual observation does identify the presence of macro-biofouling, IWC is then implemented. Since it is expected that improved antifouling products will have a high antifouling effect, it is expected that observation on almost all commercial vessels for at least 1 or 2 years will be conducted and IWC implementation will not be needed.

7.0.10 The reason IWC is immediately implemented whenever macro-biofouling is observed is because egg production by any sexually mature organisms attached can increase the amount of organism transfer. Since the sexually mature organisms are usually several centimetres or more in size (radius), such macro biofouling is relatively easy to detect. Visual inspection is then used to decide whether IWC implementation at intervals of one year or less is needed in general sea areas. Setting the interval for visual inspection at one year further reduces the amount of organism transfer by IWC by ensuring that shuttling of vessels with macro-biofouling are limited as much as possible. If IWC is to be implemented all around the world, any sexually mature organisms present should also be collected. The obligatory collection of all IWC-removed materials is expected to completely eliminate organism transfer at the global level. A ship that is treated with AFCS products and also has a MGPS device/treatment (approved as a highly effective antifouling device) in place can be allowed to remain at sea without inspection for more than one year. However, if macro-biofouling is detected at shorter intervals, IWC should be implemented immediately.

7.0.11 During the inspection carried out by the country controlling a given port (port state control: PSC), inspectors should investigate the presence of any biofouling organisms for themselves. PSC includes the verification of control records, i.e., confirmation of antifouling treatments applied, work records for the systems in use, and observation and IWC implementation records.

7.0.12 Important tasks that need to be addressed in future are the test methods needed to evaluate the required performance of antifouling and removal systems, and the assessment method and criteria needed to deal with environmental risks. These issues and procedures are not yet internationally unified, or performed by manufacturers alone. In order to establish a fair and clear control and operation system in the future, these issues need to be resolved. A further issue is the need to expand the current IWC system and to secure the necessary facilities and equipment to implement IWC and IWC processing companies, worldwide.

7.1 Definition of the terms and treatment techniques involved in the use of the proposed comprehensive antifouling control system and its evaluation

7.1.1 Definition of terms

(1) Definition of terms used in this report

Examples of definitions of the terms used in this report are listed again in Table 7.1-1. These terms have already been defined and used in Chapters 1 to 6, above, but are listed again here for reference purposes.

The definitions of these terms, as used in this report, are based on the definitions used in the draft "Guidelines for the control and management of ships' biofouling to minimize the translocation of invasive aquatic species" proposed by the IMO. However, some of these terms are newly defined in this report, and so the definition of terms in this report is not always correspondent to the IMO's definition, especially when considering their future use in a comprehensive antifouling control system.

Table 7.1-1 Definition of terms related to the comprehensive control of biofouling by alien species

Term	Definition used in this report
Active substance	A chemical substance that has a killing/growth-inhibiting effect on hazardous marine species and bacteria and preventing larva attachment or their combination
Anti-fouling coating system (AFCS)	AFS device and treatment to prevent and remove biofouling organisms and AFCS is an important component of any AFS, as well as MGPS. At present, antifouling paints are the most common AFCS treatment to prevent biofouling. Ship cleaning and IWC in dock, which are conducted for removal of biofouling organisms and renewal of antifouling paint, are also classified into AFCS. Similar treatment techniques applied to components other than the outer hull plating are classified into the MGPS.
Anti-fouling system (AFS)	Anti-fouling system (AFS) is roughly classified into antifouling treatment and removal techniques of biofouling organisms, in terms of the measures to control biofouling organisms. AFS consists of AFCS and MGPS in terms of the device/treatment by ship component.
Biofouling	Biofouling: the accumulation phase of aquatic organisms on the soaked ship surface (including not only the area under the water but also the area exposed to splashing water). Biofouling includes 2 developmental stages: micro-biofouling and macro-biofouling. [In this report, the term “soaking” is used but not “dipping”.]
Clean ship	This term is not used in this report. Instead, the expression "the ship surface that does not attain the macro-biofouling phase" is used.
In-water cleaning (IWC)	In-water cleaning (IWC): the physical removal of biofouling organisms from outer hulls in water and the removal of organisms attached to complex ship parts other than the hull skin In this report, IWC for hull skin is classified into the AFCS, IWC for other components into the MGPS.
Macro biofouling	The phase of biofouling development in which visible multi-cellular organisms attach and grow on the soaked ship surface. This is the next stage on from micro biofouling. Macro-biofouling is composed of multi-cellular organisms including barnacles, sand worms and large seaweed species and associated debris, shells etc.
Marine growth prevention system (MGPS)	A technique used to prevent and remove organisms attached to the seawater circulation system in a ship and to complex components such as the sea chest. In this report, it is considered as a marine species antifouling system. The seawater electrolysis system is the most important MGPS and includes the use of and a steam injection system and use of active substances. Antifouling treatment for ship components except hull skin is also classified into the MGPS. Similar treatment techniques applied to the outer hull plating are defined as AFCSs.

Table 7.1-1 Definition of terms related to the comprehensive control of biofouling by alien species

Term	Definition used in this report
Micro biofouling	The phase of biofouling development in which the hull surface is coated with bacteria, microscopic unicellular protoctista such as diatoms, and slime substances generated by these organisms (usually extracellular polysaccharides).
Risk of aquatic species transferring	Risk that species is transferred into a distant area from their native area by human actions (establishment). The case a species is transferred and successfully reproduces, species is defined as species invasion. In this report, the risk of species transferring is evaluated on the basis of the amount (dose= the number of organisms or egg production).
Risk of invasion	The risk (probability) that a certain species will be transferred from its original habitat by human-related mechanisms such as marine transportation and settle in a distant sea area, consequently threatening humans, plants and animals, economic and social activities, and the marine environment.
Slime layer	A layer generated by microorganisms such as bacteria and diatoms, unicellular protoctista and comprising slime substances (usually extracellular polysaccharides).
Cleaning of ship components in dock (dry dock)	Cleaning of ship components in dock not but IWC in water or for a ship anchoring in harbor. In this report, cleaning of hull skin in dock is classified into the AFCS, and cleaning of ship components except hull skin into the MGPS.
Antifouling paint	A paint to apply hull skin and other complex components for prevention of biofouling. Antifouling paints consist of a biocide-based paint that contains toxicity to aquatic organisms and release active substances from painted surface and a biocide-free paint that prevents biofouling due to smoothness and water-shedding properties. Biocide-based paints that are currently used in Japan include self-polishing, self-degrading and conventional paints and the most common is self-polishing antifouling paint.

Taking the IMO's latest definitions into consideration, any terms newly defined in this report are based on the Japanese government's comments.

(2) Terms related to the control system

Table 7.1-2 shows the terms used in the proposed standards and guidelines for the comprehensive control of biofouling organisms, as studied in this survey, and their definitions. These terms and definitions are not internationally agreed on at present. Those terms that currently have no definitive definition and those related to new techniques and standards (new definitions) may need to be more clearly defined in the future. In particular, the assessment method for organism invasion (level) and the introduction of special sea areas should be further clarified.

Table 7.1-2 Definition of terms related to requirements for the comprehensive control of biofouling used in this report

Term	Definition
Performance standards	The standard for the antifouling performance of AFCS and MGPS and for each device/technique used to prevent or remove biofouling AFCS and MGPS are specified by the performance standards for preventing macro-biofouling, facilitating environmental risk assessment, etc. IWC is specified by the performance standards for collecting IWC-removed materials, minimizing the severity of damage to AFCS-processed surfaces Since this is a standard for the performance of each device/technique, it is assured by the type-approved performance specifications obtained from the manufacturer of each device/technique, but is not dependent on the operation conditions, etc.
Application standards	The application standards are the standards that specify the procedures for applying each AFS device/treatment meeting the performance standards for a ship during construction/docking to the corresponding ship component in order to maintain the performance of AFS after applying to ship components. The standard for the performance of AFCS products applied to the outer hull plating and MGPS devices used for complex components as a technique to prevent biofouling. An IWC device that meets a specified performance standard per ship component is specified as a suitable technique to remove biofouling organisms.
Operation standards	Operation standards are applied for the installed device/technique that meets the desired shipping requirements. The standards specify the frequency of operation (use) of each device/technique are in accordance with the performance standards and the combination of devices/techniques used. The operation standard for the removal of biofouling organisms specifies the duration (frequency) of in-water inspection by licensed diver(s) and the criteria used for IWC implementation. The performance and application standards required for general and special sea areas are the same, but the operation standards are different.
General sea area	Sea areas around the world, except for special sea areas
Special sea area	A vulnerable area easily affected by the invasion of alien species or an area which ecologically valuable species inhabit as native species. The operation standards for special sea areas are different from those for general areas. It is assumed that the establishment of such areas will be approved by international organizations such as the IMO.

7.1.2 The relationship between the various control techniques (anti-fouling system: AFS) evaluated in this survey

The relationship between the various AFS techniques evaluated in this survey is shown in Figure 7.1-1. In this survey, AFS can be broadly classified into either the "prevention of biofouling" or "removal" categories. AFCS is evaluated by component as a technique for use on the outer hull skin and MGPS is regarded as a technique for use on complex components such as the sea chest and components other than the outer hull skin. For example, antifouling paints are applied to both hull skin and complex components, however, the former is considered to be AFCS and the latter MGPS. Removal treatment is classified into ship cleaning in dry dock and IWC at sea, however, the applied parts are not different and the same device is sometimes used.

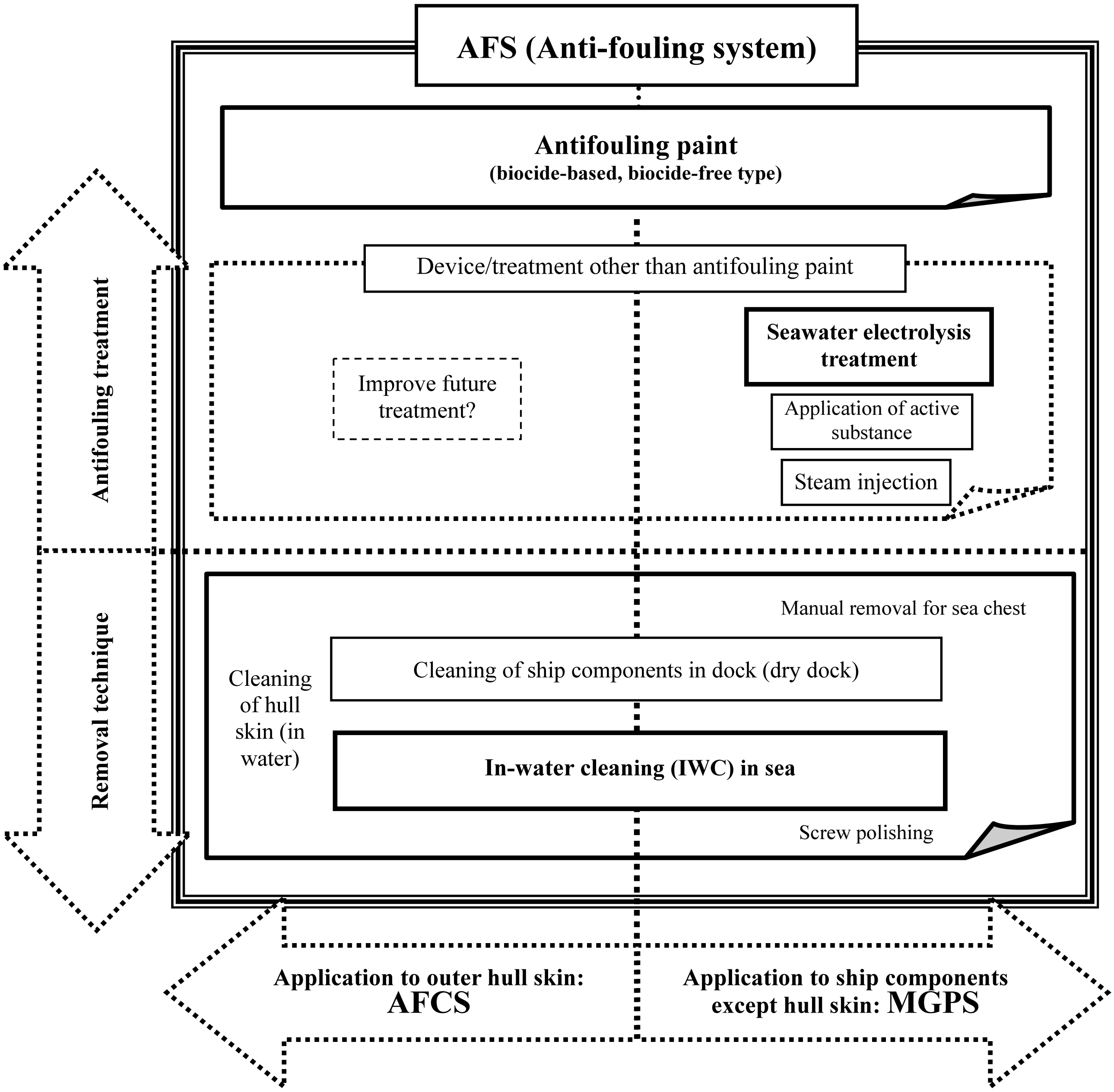


Figure 7.1-1 Correlation diagram for the anti-fouling system (AFS) evaluated in this survey

7.1.3 Control treatments, chemical risks and the risk of organism invasion

In this report, various current and future antifouling treatments (Chapter 3) and removal treatments (Chapter 4) were evaluated as control techniques. Furthermore, the chemical environmental risks associated with antifouling and removal treatments (Chapter 5) and the risks of organism invasion (Chapter 6) were also evaluated - including treatments that are expected to improve in the future.

The test subjects used for evaluation of the control techniques, chemical risks and the risks of organism invasion are listed in Table 7.1-3. Chemical environmental risks and the transfer (amount) of alien species, as described in Chapters 1 to 6, are basically interrelated. For example, if the antifouling effect of a self-polishing AFCS on organisms is increased, the chemical risk to the surrounding environment simultaneously increases. Therefore, in the development of a comprehensive antifouling control system, based on the results of this survey, it is important to combine the operation of valid and feasible treatments, taking both the risk of organism invasion and chemical environmental risks into consideration.

With regard to those techniques given a C or B rating in the following table, the interrelated chemical environmental risks and transfer amounts for organism invasion, under current conditions, were analyzed and also evaluated in terms of conditions likely to be encountered in the future. However, techniques that already had an apparently low level of risk, both at present and in the future, and techniques that required no further improvement or could not be quantitatively evaluated were excluded from this evaluation.

Therefore, it should be noted that not all the techniques listed were evaluated fully as part of this comprehensive control system and the appropriate regulations have not yet been established.

Table 7.1-3 Subjects for evaluation in this survey

Control technique	Treatment	Current evaluation	Evaluation of future improved comprehensive control technique
Antifouling treatment	Application of antifouling paint to hull skin	T, C, B	T, B, (C)
	Application of antifouling paint to components other than hull skin	C	*
	Application of treatment/device other than antifouling paint to hull skin	T, C, B	T, C, B
	Application of treatment/device to other than seawater electrolysis system to components except hull skin	*	*
Removal technique for biofouling organisms	Cleaning of ship components (including hull skin) in dock	T	T
	IWC implementation to hull skin	T, C, B	T, C, B
	IWC implementation for components other than hull skin	T, B	T, B

T: evaluation of treatment application or improvement, C: evaluation of chemical environmental risks, B: evaluation of the transfer amount of organisms

* Excluded from the evaluation carried out in this survey because neither the current nor future technique has been clearly established yet or exposure scenario for quantitative risk assessment cannot be established.

7.2 Overview of a comprehensive antifouling control system

7.2.1 Background

Many cases of economic damage caused by biofouling alien organisms and cases of damaged ecosystems disturbed by alien species have recently been reported, although the amount of damage to human health is not yet clear. In Japan, many cases of damage have also been reported and it should be assumed that the amount of damage caused by biofouling organisms is increasing worldwide. Taking all this into consideration, a comprehensive biofouling control system should be established as soon as possible in order to facilitate the adoption of global countermeasures. In addition, the above system must be acceptable to the shipping industry in terms of cost and feasibility.

In general, a control system adopted by international organizations can either be an international voluntary system with established guidelines and ISO standards or an enforceable system including international conventions and new annexes, etc. In this survey, it is assumed that the latter, enforceable type of system will be adopted. This is because the contents of a voluntary system are likely to vary in accordance with the different laws and regulations of different countries and areas. Consequently, the international marine market, a single market, is distorted and unstable.

The IMO is currently developing draft "Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species". These guidelines are voluntary and have no power over ship owners, shipyards and shipping agents. Therefore, if many ongoing cases of damage are still reported after the establishment of these guidelines, it is fully anticipated that the voluntary-based guidelines will be considered insufficient and replaced with enforceable regulations.

The reason for proposing a comprehensive control system in this survey (based on the assumption that an enforceable framework will eventually be put in place) is so that an evaluation can be carried out based on scientific evidence in order to generate suitable results to support any future discussion regarding international regulations. Furthermore, this proposal could also act as a suitable road map to develop the necessary techniques and evaluation methods required to support the regulations.

When enforcing international standards, it is important that any additional burden imposed can actually be accepted by the shipping agents. In particular, when regulations and controls are as strict as the Ballast Water Management Convention, the economic burden imposed on shipping agents in order to comply with the regulations can be substantial and can have a significant effect on the effectiveness of the regulations (such as ratification in the case of a convention). Consequently, the damage caused by species invasion may actually increase due to the delayed implementation of suitable countermeasures. The reason why the issue of regulations being acceptable to the shipping industry is discussed in this report is that an immediate approach to the shipping industry is important in order to prevent any further delay and resultant increase in risk.

7.2.2 Concept of the comprehensive antifouling control system

(1) Difference between performance, application and operation standards

The development of the control system proposed in this report is based on the adoption of 3 sets of standards (performance, application and operation standards) due to the specificities of the ships involved and the difficulties associated with organism monitoring.

The first set of standards, the performance standards, is used to evaluate the performance of products/devices included in AFSs (AFCS, MGPS and IWC products/devices in particular) and to obtain the model approval in advance. The products/devices that meet the performance standards and obtain the required type approval can then be applied to AFS use. However, in practice, not every AFS system/technique may always meet the required performance standards under actual conditions of use.

In the treatment framework described in this report, IWC is defined as a component of AFS. Therefore, any system used in IWC must also be approved and specified by the model, in a similar manner to that used for AFCS and MGPS.

The second set of standards, the application standards, is used to specify the AFS to apply during shipbuilding and the coating to be re-applied when in dock, with regard to each individual ship component.

The third set of standards, the operation standards, is used to specify the minimum standards or conditions when using AFS on an actual ship. These operation standards include the frequency of IWC implementation (or alternative measures).

The above framework may appear complicated, but its advantages can be understood in comparison with the framework of the Ballast Water Management Convention. The Ballast Water Management Convention has not yet come into effect in 2010, even though it has been 6 years since the convention was established in February 2004. The major reason why this convention has not yet come into effect is that the convention requires that all signatories ensure that the emission water standards in actual sea areas meet the same standards as those used for the initial model used for approval. To be specific, as part of the port state control (PSC) procedures for foreign ships, an inspector of the country controlling a given port collects a sample of ballast emission water, determines the release concentration (organism density) and confirms whether or not the emission water has been appropriately treated in comparison with the release concentration (organism density), as specified in the type approval. It may be reasonable to apply the same standards to test both emissions and the actual sea area. However, the concentrations of chemical substances in exhaust gas and water may be different from the standards for ballast water, which are specified in terms of organism concentrations and are unlikely to confirm the desired level of performance in actual sea areas due to measurement errors, even when products/devices that have been approved on the basis of strict performance standards have been appropriately applied to the ship in question. Therefore, the comprehensive biofouling control system proposed in this survey specifies the use of two separate inspection items to confirm AFC in PSC, [1] an international certificate, and [2] records that ensure that the relevant standards and conditions have been met, as specified separately by the operation standards.

The main reason why the application standards are specified separately is that the AFCS and MGPS appliers are assumed to be different from the manufacturers. AFCS, especially, cannot be expected to provide optimum performance if AFCS not appropriately applied. In addition, combinations of AFCS and MGPS that are approved by different manufacturers may develop the best AFS system or a comprehensive control system.

In consideration of all the above factors, the application standards have been specified separately because shipyards play an important role in the application of AFS to ships, as well as the AFS manufacturers. Each ship is required to have certificates describing the AFS type approval and the specific AFS application on board.

(2) Concept of performance and application standards

a) International uniformity

The performance and application standards should be internationally unified in order to avoid creating confusion within the shipping industry.

b) Compatibility of antifouling performance and chemical risk

The performance standards consist of standards for antifouling performance and allowable levels of chemical environmental risk. Improved antifouling performance may increase chemical environmental risk. Therefore, the performance standards must confirm that both improved antifouling performance and allowable levels of chemical environmental risk are maintained.

c) Specification by ship component

The performance standards for AFCS products/devices are specified separately for complex components such as the sea chest, which generally exhibits severe biofouling, and outer hull plates with relatively lower levels of biofouling.

As described in "Chapter 2 International trends regarding regulations", the draft "Guidelines for the control and management of ships' biofouling to minimize the translocation of invasive aquatic species", which the IMO is currently developing, state that the characteristics of individual ship components should be considered when selecting which antifouling system to use. Therefore, the draft guidelines recognize that antifouling performance differs between different ship components. This is the major reason why the performance standards are specified for individual ship components in this system.

It is also important to reduce the total risk of organism transfer and the chemical environmental risk on a component-by-component basis. It is appropriate to establish different performance requirements for the outer hull plates and the sea chest, which exhibit different biofouling characteristics. Different performance standards apply to each system and can assess risks separately on either outer hull plates or complex ship components, leading to the establishment of higher leaching rates for the latter than for the former in AFCS.

In recognition of the above factors, the comprehensive biofouling control system proposed by this survey can specify different performance characteristics for different ship components.

Furthermore, the comprehensive biofouling control system proposed in this survey would also allow internationally uniform test procedures to be established to assess whether each ship meets the required standards and facilitate the international standardization of test procedures required for the implementation of operation standards based on the performance standards.

(3) Operation standards and special sea areas

It is basically preferable for the operation standards to be internationally agreed and uniform all around the world, similar to the design standards and application standards. However, it is likely that different operation standards will be required for very vulnerable sea areas in which native ecosystems are easily affected by the invasion of alien species or where chemical environmental risks will have a major effect on native species. In this report, the term “special sea area” does not mean a sea area where shipping is limited, such as the particularly sensitive sea areas (PSSA) defined by the IMO, but a vulnerable sea area surrounding a port frequently used by commercial vessels and a sea area that requires protection due to its biodiversity (called a “Hot Spot”). The decision on whether or not a sea area surrounding a port is vulnerable and the extent to which such a sea area should be considered a special sea area is often subjective and depends on the relevant country's views on coastal ecosystems and the relationship with local fishing organizations. Therefore, it will probably be difficult to reach an international agreement.

To avoid such a situation arising, and to reduce the burden of organism transfer as soon as possible, internationally, it may be more effective to allow each country/region requiring strict standards to designate special sea areas themselves and establish different application standards for these special sea areas. On the other hand, for those countries/regions that do not designate special sea areas, it would be preferable to establish and immediately implement a set of unified operation standards to reduce the burden of organism transfer and avoid any ecosystem disturbance.

Even if special sea areas are designated, AFCS and MGPS should still be applied to ships in accordance with internationally agreed performance and application standards. Different practical requirements include the frequency of re-application (update) of AFCS and MGPS, and the frequency of implementation of IWC and alternative devices.

(4) Countermeasures for offshore waiting

In some ports, ships sometimes wait for loading/unloading offshore, while anchored near a port. Offshore waiting occurs when shipping demands exceed the loading/unloading capacity of port facilities. Therefore, the port at which offshore waiting occurs and the ship type that is forced to wait depend largely on the international economic trends and the status of infrastructure construction, and it is difficult to predict future conditions. If early implementation of IWC is adopted, the IWC-related cost burden will become a concern for both shipping agents and their clients. It is known that offshore waiting increases biofouling on ship hulls and the results of the estimation carried out using offshore waiting models in "Chapter 6 Risks of species transfer" suggested that offshore waiting increased not only the risks of species transfer in the country where ships wait offshore but also the risks of alien species transfer in other countries. Consequently, offshore waiting should basically be avoided as much as possible. To prevent long-term offshore waiting, it will be necessary for all IMO member countries to recognize the increased risks of species transfer and the associated chemical risks and make ongoing efforts to prevent offshore waiting in the future.

7.2.3 Overview of a comprehensive antifouling control system

(1) Techniques comprising the control system

In Chapters 1 to 6, the techniques evaluated as effective components of a comprehensive antifouling control system were as follows: [1] Antifouling paints with improved antifouling performance (AFCS when applied to hull skin, and MPGS in other cases), [2] seawater electrolysis system with improved antifouling performance, and [3] in-water cleaning when antifouling treatment cannot prevent biofouling (IWC, removal treatment). An overview of these techniques is provided below.

a) Antifouling treatment

i) antifouling paint with improved antifouling performance

Self-polishing antifouling paint, the most commonly used antifouling paint, is considered to be the best way of applying paints with different levels of antifouling performance to the hull skin, which have a large surface area (considered to be AFCS) and relatively little biofouling, and to the sea chest (considered to be MGPS), which has a small area and severe biofouling and control risks by component because antifouling performance competes against chemical risks. Specifying different levels of application performance for different ship components is expected to balance reduce biofouling and chemical environmental risks.

Since silicone-based AFCS does not leach eco-toxic active substances, it may be applied as products for both AFCS and MGPS if issues related to the cost and durability of application are solved.

ii) Seawater electrolysis system with improved antifouling performance

The seawater electrolysis system was originally developed as a device for use on the inner piping of cooling water systems. However, considering its mechanism and current usage conditions, it should also be possible to use seawater electrolysis systems on the sea chest. To be specific, a seawater electrolysis system employing a modified concentration and injection method can decrease the amount of organisms attaching to the sea chest, leading to a reduction in the burden of organisms transferred via the sea chest. In theory, this system can also be applied to the outer hull plates, however, the system uses and produces large amounts of chlorine compounds and so there are chemical environmental risks concerned with its ecotoxicity. Therefore, it is understandable that the application of the seawater electrolysis system is currently limited to closed sections of ships, such as the sea chest and inner piping of the cooling water system, and not used on the outer hull plates.

b) Removal treatment

In "Chapter 6 Risks of species transfer", it was concluded that IWC implementation decreases the number of biofouling organisms and the number of eggs that are spawned by organisms that attain sexual maturation after attachment. However, IWC implementation simultaneously increases the number of biofouling organisms that are removed and released into sea areas. On the other hand, it was found that egg production from organisms removed by IWC was less than that from sexually mature organisms attached to hull plates and that IWC implementation, therefore, decreased the overall burden of organism transfer by egg production.

In the assessment of chemical environmental risks carried out in this survey, it was concluded that IWC implementation does not excessively increase chemical environmental risks. In future, the incorporation of efficient collection of IWC-removed materials as part of IWC implementation could be expected to minimize any possible increase in chemical environmental risks.

In "Chapter 6 Risks of species transfer", it was suggested that IWC implementation without collection of IWC-removed materials increases the burden of organism transfer in a country with IWC implementation if some countries/regions (sea areas) ban IWC (special sea areas) while others still permit IWC implementation. Therefore, based on the need for a comprehensive and international control system, it was concluded that IWC should include the collection of all IWC-removed materials. Simultaneously, as part of a comprehensive control system, it may also be necessary to consider the protection of rare species and countries/regions that are particularly vulnerable to species transfer.

(2) Overview of standards required by the control system

a) Performance standards

The performance standards specify how treatments should be applied to ships and the required performance of the devices used. The performance standards specify the performance of the antifouling and removal effects required and the criteria regarding environmental risks (see Figure 7.1-1 and Table 7.2-1). Products, devices and treatments for which the performance standards are established include the following 3 systems: AFCS products applied to outer hull plates, the seawater electrolysis system (a MGPS applied to complex components such as the sea chest), and IWC used for the removal of biofouling organisms. Other treatments are not currently included as test subjects in the performance standards for the control system. The performance standards for the proposed comprehensive antifouling control system (draft) are shown in Table 7.2-2. The ranks specified by the performance standards are shown in Table 7.2-3 and Table 7.2-4.

Products/devices must be evaluated in an internationally agreed manner prior to their application to ships to ensure that their level of performance meets the specified standards. It is preferable for business organizations to discuss and establish the required performance levels, tests and assessment methods needed with regard to environmental risks. The performance standards will only be finalized after the MEPC/IMO, etc. establishes the necessary standards. However, the initiation and establishment of a voluntary control system prior to the adoption of international regulations will assist their development and contribute to the creation of enforceable, effective and comprehensive regulations based on this system.

The performance standards for each subject system and treatment will need be approved by the relevant supervisory authorities or organizations. When applying the seawater electrolysis system to the sea chest, for example, in consideration of the effect of anticipated release volumes on the marine environment, the performance of each seawater electrolysis system should be evaluated by a third-party organization and approved by the IMO, similarly to the Ballast Water Management Convention. The collection device should be attached to all IWC devices (with all sexually mature organisms having to be collected).

Table 7.2-1 Application treatment for each ship component

	Outer hull plates	Complex component (sea chest, etc.)
Antifouling treatment	Application of AFCS products	Application of MGPS devices: seawater electrolysis system, injection system, sacrificial electrodes, etc. (exception: application of AFCS to the sea chest)
Removal treatment	IWC implementation to outer hull plates and collection of IWC-removed materials Cleaning of hull in dock	IWC implementation on complex components and collection of IWC-removed materials e.g. manual removal of biofouling and collection of IWC-removed materials Screw polishing, etc.

Table 7.2-2 Performance standards in the comprehensive antifouling control system [1] (draft)

AFCS (System/treatment applied to outer hull plates)	**MGPS** (System/treatment applied to complex components)
AFCS product (antifouling paint): antifouling treatment 1) Required performance Required performance is classified into 2 levels: Ranks 1 and 2.[2] 2) Criteria regarding environmental risk A leaching test should be conducted in exposure scenarios, taking into account the IWC-peeled coating film (regardless of whether biocide or silicone-based products are used) in order to identify any leached substances present and determine the maximum detection concentration. If no leached substance is detected, the following tests are exempted. If an leached substance is detected, combined toxicity tests in 3 typical aquatic species (algae, crustacea and fish) should be conducted to confirm that the risk to the surrounding ecosystem is allowable. e.g., In combined toxicity tests, it should be experimentally confirmed that the NOEC for all species in acute toxicity studies is higher than the concentration found in a test solution diluted to [aa %].	**MGPS device and treatment (including seawater electrolysis, antifouling paint and their combination): antifouling treatment** 1) Required performance Required performance is classified into 2 levels: Ranks 1 and 2.[2] 2) Criteria regarding environmental risk In conformity with the criteria for AFCS product . (However, an exposure scenario is constructed for MGPS).
IWC device: a device to remove biofouling organisms [3] 1) Removal performance All macro-biofouling must be completely removed.[4] 2) Collection performance Devices with the required level of performance and which are practical and currently available should be used. Devices that can collect removed materials of [bb mm] or more (the size of the collection net) should be used. 3) Assessment of the effect on the coating film[5] When removing attached materials using an IWC device, the effect on the coating film (the amount of coating film peeled off) is assessed in a test. The removal of more than cc μg/cm^2/min of coating film per unit area per hour of IWC is not permitted.	

---

[1] The performance standards are submitted by the manufacturer and approved (by model) in advance.

[2] For ranks, see Tables 7.2-3 and 7.2-4.

[3] The performance standards assume the use of biocide-based AFCS. For silicone-based products, another test and evaluation standards are required.

[4] In the test for type approval for the performance standards of each model, it is necessary to use a test plate for the artificial standard of macro-biofouling.

[5] The assessment criteria to test the IWC effect on coating films are specified separately by the IMO (in terms of the active substances in AFCS products).

Table 7.2-3 Performance required by AFCS products (draft)

Classification of required performance	Required performance
Rank 1	No macro-biofouling is observed on a test plate with AFCS product applied and soaked in natural seawater when visible plants and animals are observed on the surface of an undercoated (corrosion proofing paint) steel plate similarly soaked in the control section (at [A1%*] or more).
Rank 2	No macro-biofouling is observed on a test plate with AFCS product applied and soaked in natural seawater when visible plants and animals are observed on the surface of an undercoated (corrosion proofing paint) steel plate similarly soaked in the control section (at [A2%*] or more).

* The bio-covering percentage specified in Rank 1 is smaller than that in Rank 2.

Table 7.2-4 Performance required by antifouling paints (draft)

Classification of required performance	Required performance
Rank 1	No macro-biofouling is observed on a test plate after seawater that is continuously taken from the control section is treated with the device when visible plants and animals are observed on the surface of an undercoated (corrosion proofing paint) steel plate soaked in natural seawater (at [M1%*] or more).
Rank 2	No macro-biofouling is observed on a test plate after seawater that is continuously taken from the control section is treated with the device when visible plants and animals are observed on the surface of an undercoated (corrosion proofing paint) steel plate soaked in natural seawater (at [M2%*] or more).

* The bio-covering percentage specified in Rank 1 is smaller than that in Rank 2.

The reason why the two ranks, shown above, have been established is that biofouling is often more severe in the sea chest than in the inner piping system and, therefore, the sea chest requires higher antifouling performance. When enforceable regulations are adopted, products whose performance is confirmed to be Rank 1 or 2 will be approved and appropriate certificates issued without reapproval.

With regard to devices used to treat the sea chest, different levels of performance will be required from a device that is assumed to be used in combination with any AFCS products, in general, regardless of antifouling performance or the composition and amount of the active substances, or can be used in combination with a specific AFCS product.

In the case of a seawater electrolysis system that is used in combination with any AFCS products, it must be confirmed that no biofouling is observed on an undercoated test plate (corrosion proofing paint), in comparison with a test plate in the control section, when exposed to seawater passing through (treated with) the device. When used in combination with a specific AFCS product, a test plate processed with the specific AFCS product is compared with an undercoated test plate in the control section. Any seawater electrolysis system that can be combined with any AFCS product is required to have a higher antifouling performance.

It is preferable that any test methods used for performance assessment and the test result themselves (coverage, expressed as a [%]) are discussed with and established by the relevant business organizations, etc.

IWC must be able to remove all macro-biofouling and not damage (remove coated films) on any AFCS-processed surface. Furthermore, the IWC method used must be capable of collecting all IWC-removed materials. The collection of IWC-removed materials is very important in order to reduce both organism transfer and chemical environmental risks. Therefore, the performance standards must specify that all IWC-removed materials are to be collected.

Chemical environmental risks specified by the performance standards should be assessed for all AFCS products, the seawater electrolysis system and IWC, and approved in advance before any application to ships. Chemical environmental risks are assessed using the PEC/PNEC ratio, a commonly used indicator. However, an exposure scenario to estimate PEC should also be established for the worst possible case. To assess the risks of AFCS products, both the leaching rates of active substances from the ship's surface and combined toxicity studies of active substances and leaching substances (whole effluent toxicity: WET) need to be considered.

The assessment methods for environmental risks, including toxicity studies, are in accordance with the IMO's standards and make use of a standardized process in which all distributors' views are considered. It is preferable that international business organizations, etc. start the standardizing process, themselves, prior to official standardization by the IMO.

The chemical environmental risks of IWC are not included in the type approval of the device/model required by manufacturers if an IWC device meeting the performance standards is already in use, in accordance with the criteria (observation and IWC frequency) specified by the operation standards.

b) Application standards

The application standards (draft) are shown in Table 7.2-5. The application standards specify the antifouling and removal devices and treatments to be used for each ship component. Therefore, the application standards specify the devices and treatments to be used for [1] outer hull plates and [2] complex components such as the sea chest.

Table 7.2-5 Application standards for use in the comprehensive antifouling control system (draft)

Outer hull plates	Ship component (except outer hull plates) [6]
Antifouling treatment AFCS products with specified performance standards (rank) for type approval	**Antifouling treatment** MGPS system/treatment (or their combination) with specified performance standards (rank) for type approval
Removal device for biofouling organisms IWC system/treatment (or their combination) with specified performance standards (rank) for type approval	

c) Operation standards

The operation standards (draft) are shown in Table 7.2-6. The operation standards are applied to the observation of biofouling conditions, measures based on the observation results, and inspections carried out by the country controlling the port (PSC) whenever a new AFS is applied to ships.

Each system/device applied obtains type approval if it meets the specified performance standards. Therefore, AFCS products and devices that are already in use on or in a ship are excluded from the operation standards. The operation standards are not applied to the products and devices themselves in this case is because, as described above, the performance standards are not applied to a ship at sea, in order to avoid any unnecessary confusion. With regard to divers in charge of the observation of biofouling conditions, a licensing system is needed to confirm whether or not their observation ability is adequate.

The operation standards for AFCS need to include different standards for self-polishing AFCS containing active substances and silicone-based AFCS. However, the ranking of the performance level required is the same. The operation standards should also be practical and not incur excessive cost (taking into consideration the combination with the seawater electrolysis system and its application to different ship components, as specified by the

---

[6] The application standards (by component) are specified separately by the IMO.

application standards).

The operation standards include macro-biofouling, the period of time between the latest dock visit and the next scheduled inspection of the ship's surface, and the IWC interval.

If offshore waiting occurs, due to some unavoidable circumstance, the time interval until the next diver's inspection should be shortened in accordance with the period of offshore waiting involved, based on the decision of the PSC.

In order to establish a comprehensive international control system, each country/sea area with rare species or areas that are especially vulnerable to alien species transfer may be allowed to have different operation standards from those used for general sea areas.

The main focus of biofouling control in this survey was macro-biofouling. However, depending on the results of further studies, it may also be found the necessity to control micro-biofouling. On the other hand, it is difficult to appropriately control micro-biofouling with currently available treatment/device. If, however, the invasion of alien species via micro-biofouling is reported in the future and evidence of such biofouling organisms is confirmed and the measures for risk control is needed, measures to control micro-biofouling will need to be discussed on development of new system and treatment and improvement in the current ones, furthermore, review of operation standards.

Table 7.2-6 Operation standards for use in the comprehensive antifouling control system (draft)

Indicator of operation standards	To ensure that macro-biofouling is not observed.
Observation by divers	Within one year, immediately before entering dock [7] A ship that is treated with AFCS products and a seawater electrolysis system that are evaluated as Rank 1 can be allowed to carry on for longer before needing inspection by divers (at the discretion of the PSC).
	Implementation of observation by licensed diver(s) to inspect for macro-biofouling, or any similar method approved by the IMO member countries in advance. Observation by diver(s) is not always required within 6 months after IWC implementation, regardless of the period of time elapsed after docking.
Criteria for removal of biofouling organisms [8] (IWC and other systems/treatments)	If macro-biofouling is observed by diver(s), or by any other method, IWC is implemented immediately. Or, if macro-biofouling is observed by another method and immediate IWC implementation is considered necessary, biofouling organisms are then removed by IWC. IWC may be implemented in any area (i.e., not limited to the sea area where macro-biofouling is observed). The operation standards for ship components other than outer hull plating are specified separately by the IMO.
Inspection by the country controlling a port (port state control: PSC)	Verification of control records, i.e., confirmation of antifouling treatments applied, work records of the systems used, observation and IWC implementation records.
Additional standards for offshore waiting	If offshore waiting occurs due to unavoidable circumstances, the period of time until inspection by divers is shortened in accordance with the period of offshore waiting, based on the decision of the PSC.

It is basically preferable that common operation standards are internationally agreed and implemented all around the world, similar to the design standards and application standards. However, it is likely that different operation standards will be required for very vulnerable sea areas in which native ecosystems are easily affected by the

---

[7] One year is a tentative period and can be changed if there is an improvement in AFCS products or other factors.

[8] The operation standards herein are applied to the removal of biofouling organisms. The operation standards for the removal of organisms attached to complex components will need to be established for each component separately.

invasion of alien species or where chemical environmental risks can have a serious effect on native species. For example, the operation standards for in-water observation and IWC frequency for such a special sea area may be different from those for a general sea area. However, the designation of special sea areas should meet the specified criteria and be subject to approval by the IMO, on application.

On the other hand, for those countries/regions that do not designate special sea areas, it is preferable to establish unified operation standards and implement a control system to reduce the burden of organism transfer and avoid confusion of the standards. However, even if special sea areas are designated, the performance and application standards will be the same as those in other general sea areas. In contrast, the operation standards can be established differently from those in other general sea areas. Thus, AFCS and MGPS can be applied the same way all around the world and the burden of organism transfer can be reduced at a global level within a framework of well-organized shipping.

The operation standards for general and special sea areas should both be unified internationally.

7.3 Tasks of the comprehensive antifouling control system

The following items were investigated and analyzed in this report. The tasks highlighted by the survey results are listed in Table 7.3-1.

Table 7.3-1 Tasks of the comprehensive antifouling control system

Chapter number and title	Major task
Chapter 1 Biofouling by alien marine species and biofouling organisms	- The mechanism of the course from organism transfer to invasion and inhibitory factors for invasion of organisms have not yet been fully elucidated. Furthermore, it is a future task to evaluate the relationship between the number of transferred organisms (egg production) and invasion risks based on quantitative indicators. Especially with regard to the mechanism of transfer for seaweed gametes and their germination, more data on actual conditions and quantitative risk assessment are required. - Based on the above, biofouling should be controlled on the basis of the treatment used rather than the characteristics of the biofouling organisms themselves.
Chapter 2 The trends emerging from discussions carried out by the International Maritime Organization (IMO) concerning the prevention of alien species invasion	- It is necessary to take voluntary measures, implemented at the guideline level, and immediately establish a convention-based enforceable control system. Therefore, the ongoing cooperation of the IMO member countries and the implementation of effective countermeasures are required.
Chapter 3 The current status of and future potential for AFS systems and antifouling devices	- It is necessary to develop and use AFCS products that pose less chemical environmental risk but have improved antifouling performance. - To fairly and clearly evaluate antifouling performance and assess chemical environmental risks, standardized test methods are required that can be implemented in conditions reflecting actual marine environments. - It is necessary to reduce the cost of antifouling and removal treatments and devices.
Chapter 4 The current antifouling paint system and technique for removing attached organisms and its potential for improvement	- The removal of biofouling materials by IWC increases chemical environmental risk. Therefore, IWC-removed materials must be collected efficiently (at as small a size as possible). - To maintain the antifouling performance of AFCS products and reduce chemical environmental risks, it is necessary to develop and use IWC devices that have less effect on the coated surface (peeling off a coated film and scarring the coated surface).

Chapter 5 Chemical environmental risks	- To accurately assess the actual environmental risk, the following accurate information is needed in order to review exposure scenarios. - Leaching rate of active substances from AFCS - Changes in the chemical structure of active substances in environments and their environmental fate - Hazard assessment of combined toxicity (WET test)
Chapter 6 Risk of species transfer	- Improved performance of AFCS products is important in order to reduce the risk of species transfer. However, in order to promote their use, it is necessary to reduce the cost of AFCS products and consider their ecological effects on surrounding sea areas. - IWC implementation using internationally unified standards can reduce the risk of species transfer. However, if some countries ban IWC, the risk of species transfer increases in any country where IWC is still implemented. - Offshore waiting increases the risk of species transfer. Therefore, measures to prevent offshore waiting are also required.
Chapter 7 Comprehensive control system for biofouling by alien species and its operation	- All interested parties should recognize the risks of species transfer and immediately establish and operate a comprehensive biofouling control system.

Final report on the comprehensive management against biofouling
to minimize risks on marine environment

Published on October 2010

Publisher: Ocean Policy Research Foundation (Ship & Ocean Foundation)

Address: Kaiyo Senpaku Bldg.,
1-15-16, Toranomon, Minato-Ku, Tokyo 105-0001 Japan
TEL : +81-3-3502-1828 FAX : +81-3-3502-2033
http://www.sof.or.jp/en E-mail : info@sof.or.jp

ISBN978-4-88404-251-6