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BALLAST WATER: ITS IMPACTS CAN BE MANAGED

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ABSTRACT

The linking of ballast water and sediment discharges with the establishment of a range of non indigenous marine organisms in various ports around the world, has focused recent attention on the identification and development of strategies to avoid further establishment of unwanted organisms. Several countries have introduced either voluntary, or mandatory regulations which seek to minimise the risks associated with discharge of water from overseas ports. A draft Australian strategy, for use with domestic ballast water is also currently under review. At the International level, the International Maritime Organisation is developing a set of draft regulations as a basis for a new Annex to the existing International Convention on Marine Pollution (MARPOL 73/78).

Although it is possible to develop an overall generalised strategy for international and national use, specific requirements may vary for different countries. These requirements will depend on many factors, including local port conditions, target organisms of interest, shipping patterns and quantities of ballast, seasonal effects, transit times, organism behaviour in ballast tanks and a host of other factors. In addition to basic management options (both proactive and reactive), based on an understanding of the factors involved, a range of physical, chemical, mechanical or biological treatment options continue to be investigated for their suitability as safe, cost effective, practical, technically effective and environmentally acceptable options. These may be used as part of the overall management "tool kit" of options to obtain the appropriate level of protection against the introduction of an organism, or group of organisms. Based on the "target" organism approach, coupled with an understanding of the conditions existing during ballasting, and in the discharge port, it is possible that only a relatively small number of ships may need to undertake ballast treatment before discharge, in some areas. This paper reviews the concept of an overall strategy, and briefly summarises some of the management and treatment aspects which have been investigated, as part of the Australian and related work, over the last 5 years.

CONSEQUENCES OF BALLAST WATER DISCHARGES AND INTRODUCTIONS

Clear evidence now exists that ships' ballast water has been a vector for the translocation around the world of marine organisms, including several toxic dinoflagellate species. In Australia, Jones[1] has attributed some 16 organisms (including one toxic dinoflagellate, *Gymnodinium catenatum*) to ballast water or sediment discharge, although hull fouling has been proposed as another vector for introduction of some marine invertebrate species. The recently observed proliferation of the Northern Pacific Starfish (*Asterias amurensis*) in the Derwent River in Tasmania, Australia, is of

major concern, although there is not yet clear evidence that ballast water has been the vector for this introduction.
At the international level, Carlton and Geller[2] have suggested that some 40 recent invasions have probably been mediated by ballast water.

Ballast water accounts for the movement of some 10 billion tonnes of water around the world annually[3,4]. This water comes from a variety of ports and locations, each having its own set of environmental characteristics. A range of conditions, such as temperature, salinity, nutrient levels and tidal conditions will determine the characteristics of the particular communities present in the ballasting ports.

The economical and environmental consequences of introduced species have been very clearly demonstrated by the proliferation of the zebra mussel (*Dreissena polymorpha*) in the waterways of the USA[4].

REGULATORY MEASURES

As a result of the establishment of foreign marine organisms in shipping ports, a range of measures have been put into place in various countries around the world in an attempt to minimise the likelihood of further spreading of these species and the establishment of new species[3]. Australia, Canada, USA, and New Zealand currently have applied the basic voluntary guidelines recommended by the International Maritime Organisation (IMO).

The IMO guidelines were issued in 1993 at the 34th Maritime Environmental Protection Committee (MEPC) session, following agreement that ballast water is now regarded as an international pollutant of major consequence. An MEPC 36 working group was formed, and is continuing to draft proposed regulations for the new annex to MARPOL 73/78 for ultimate acceptance and implementation by all IMO contracting nations. The basic guidelines seek to put in place a range of management and treatment options which are safe, effective, environmentally acceptable, and cost effective. In Australia, a National Ballast Water Strategy recently announced by the Federal Government will ensure that the Australian impetus developed by AQIS, the shipping industry and other organisations will continue in the future. In New Zealand, steps are being taken at present, to initiate the development of a National Strategy.

AN OVERALL STRATEGY

An overall management strategy (figure 1) has been suggested as a basis for the minimisation of new introductions and establishment, arising from ballast water discharges[3]. This strategy (which has not yet been adopted), involves an assessment of conditions existing in the ballasting and deballasting ports, and the implementation of various management and treatment options in transit.

Ballasting Port Conditions

An essential part of the strategy is an understanding of the conditions existing in the port, and more importantly, whether the water being ballasted contains harmful or unwanted organisms. In Australia it is recognised that, at present, it will be unrealistic to eliminate all marine organisms, and a "target" organism approach has been adapted as part of the strategy. The selection of "target" organisms is based on such factors as likelihood of presence in the water during ballasting, survival in ballast tanks, establishment (once discharged) in deballasting port, and consequences once established. This understanding, may require an effective and manageable monitoring/analysis program. Attention to ballasting practises, can also assist in minimising the amount of water, or quantity of organisms involved.

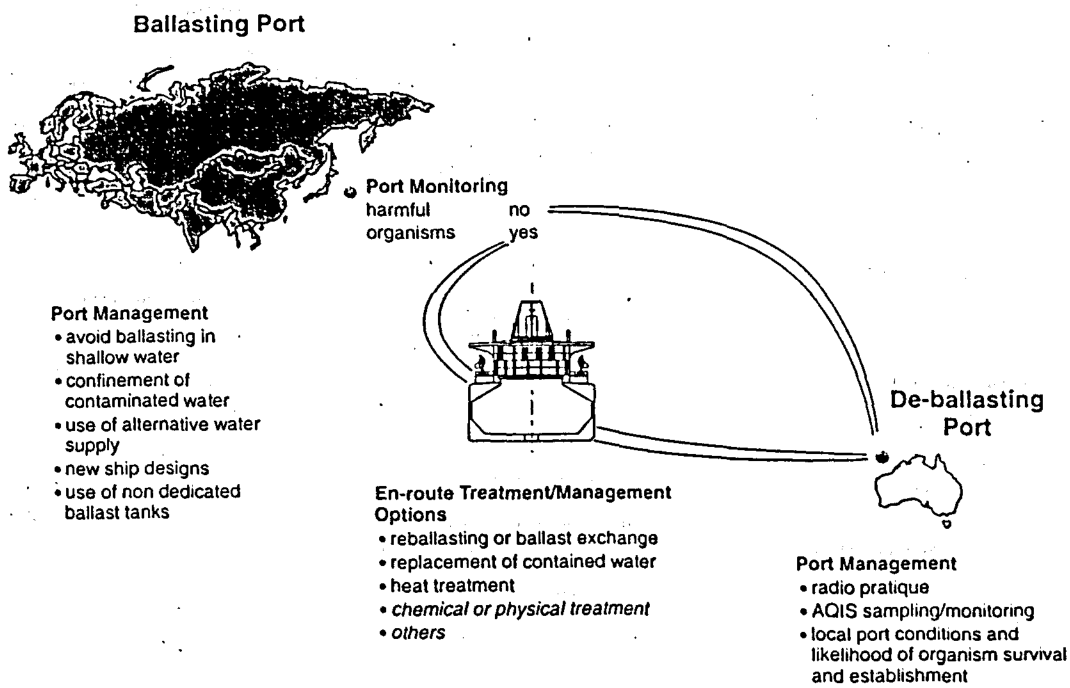

Figure 1. Overall Strategy for Ballast Water Management (from Rigby[3].)

If it can be demonstrated that the water is free of the defined organisms, the ship can then proceed to the discharging port and deballast in accordance with normal procedures involving monitoring, radio pratique and other quarantine formalities. This step avoids the need to undertake any ballast water treatment en-route. If the water is found to contain any of the "target" species, then management or treatment, involving one of the various options would need to be followed in accordance with established guidelines.

Whilst this approach may be practical for international ships bound for Australia, it may require some modification in other parts of the world. For example, for ships entering North America, treatment of ***all*** ballast water (to increase salinity levels to prescribed levels, for the control of zebra mussels) is mandatory.

Treatment/Management Options During Transit.

A range of treatment or management options have been suggested to destroy unwanted organisms[5-8].

The Australian research associated with the various options has concentrated on toxic dinoflagellates, since this was the main area of initial concern, and it was considered that techniques which could manage these organisms could also be applicable to many other organisms of potential concern. An added complication, has been that the toxic dinoflagellates of concern can produce resistant sexual cysts which can survive for long periods of time and subsequently germinate into the vegetative form under favourable conditions. Recent work by Rigby and Hallegraeff[9], has shown that the vegetative forms of many of these dinoflagellates do not survive for many days in the closed ballast tank environment, and the sexual resting cysts are not likely to form in the ballast tanks. Concerns about the toxic dinoflagellates (especially *Gymnodinium catenatum* and *Alexandrium* species) have therefore been essentially isolated to the resistant sexual cysts, since the motile cells do not generally survive in the ballast tanks beyond 3 days[9]. Ocean exchange, involving ***reballasting*** (where tanks are emptied and then refilled) and ***ballast exchange*** or ***continuous flushing*** (where ocean water is continually flushed through the tanks and allowed to overflow) can be effective at various levels (up to 100% in some cases[3]). Ship safety is a key consideration in utilising this technique (currently the most widely practised ballast control measure) to ensure that safe bending moments and shear stresses acting upon the hull of the ship are not exceeded. A set of guidelines based on the various options available for ocean exchange have been prepared as a basis for future use of this control option[10]. The Marine Safety Committee (MSC) of IMO, through a Correspondence Group (chaired by Australia) is currently reviewing the safety aspects of ballast water exchange. If a treatment option is included in the guidelines, (either voluntary of mandatory), it is essential that adequate directions and procedures be developed, and specified, to ensure optimum implementation. For example, when continuous flushing is utilised, it is recommended that at least 3 tanks volumes be replaced to yield replacement of at least 95% of the original water[9].

Initial work by Bolch and Hallegraeff[11], and Rigby and Hallegraeff[6], involving various chemical treatment options (for dinoflagellate cysts), using hydrogen peroxide, chlorine, copper sulphate and various other microbiocides, concluded that these are likely to be impractical, too expensive for general use, and in some cases, themselves environmentally unacceptable. As an example, the use of 500ppm free chlorine (required to treat dinoflagellates cysts on the BHP owned "Iron Whyalla"; 50,000 tonnes ballast water), would cost approximately $100,000. Treatment of motile dinoflagellates would require lower chemical dosages. However, even at 50ppm free chlorine, the cost of $10,000 would still be totally unacceptable for routine use. Recent work by Montani et al [12], also showed that sodium azide was likely to be too costly and ineffective against some dinoflagellate cysts. Physical treatment options, such as filtration, are able to minimise the majority of unwanted organisms but the cost for large ships (either as a ship based or shore based option) is likely to be prohibitive[3]. The cost of some of these treatments for ships involving very much smaller quantities of ballast water, may be acceptable under some circumstances.

Options involving the use of ultraviolet radiation, ozonisation and other techniques commercially used for industrial and potable water treatment are likely to be impractical (at the scale of operation required for large ships), far too costly, or ineffective against dinoflagellate cysts. Montani et al [12] have shown that germination of cysts of *Alexandrium, Gymnodinium, Protoperidinium, Scrippsiella and Gyrodinium,* at levels equivalent to at least 40% of the controls, occured after exposure to UV radiation for 2 hours. They also showed that inactivation of dinoflagellate cysts was readily achieved by use of an electric shock (100V for 5 seconds). Utilisation of this principal may be possible in some cases, and is presently under further evaluation.

The potential of inactivating toxic dinoflagellates cysts (and for killing other marine organisms) by heating ballast water has attracted recent interest as an environmentally friendly, and cost effective solution[9,11]. Initial laboratory work by Bolch and Hallegraeff[11] indicated that heating *Gymnodinium catenatum* cysts to temperatures of 40 to 45°C, for very short periods of time (30 to

90 seconds) resulted in inactivation. Heat treatment is also used as one of the basic control measures for zebra mussels in the temperature range of 33°C to 36°C, for exposure times varying from several minutes up to 2 hours[13].

Waste heat from the main ship's engine can potentially provide a cost effective source of heat. However if this option is to be used, then heating needs to take place during the sea voyage, as the ship's engine is not generally in operation during ballasting or deballasting. An analysis of available waste heat from the "Iron Whyalla" has indicated that the most appropriate means of utilising this heat would be to flush the rejected hot water (available at a temperature of 45°C) through the ballast tanks in sequence, allowing the excess water to overflow from the ballast tanks[14]. There is, however, insufficient heat available to reach a temperature of 40°C. The final temperature reached in the ballast tanks in the case of the "Iron Whyalla" (where the flowrate of hot water varies with the ocean water temperature in order to maintain a constant inlet temperature to the engine cooling circuit), will depend on the ocean temperature. For ocean temperatures between 25°C and 30°C, equilibrium ballast tank water temperatures in the vicinity of 35°C to 38°C may be possible (after approximately 48 hours flushing of each tank).

On the basis of this data, a series of further laboratory tests by Marshall and Hallegraeff[15,16], have been undertaken to examine the effects of lower temperatures for extended periods of time. This work has shown that most phytoplankton algae tested (including diatom *Skeletonema costatum,* dinoflagellates *Amphidinium carterae,* and *Gymnodinium catenatum,* and the golden brown flagellate *Heterosigma carterae*) could, in the vegetative plankton stage, be readily killed at temperatures as low as 35°C and treatment times in the range of 30 minutes to 5 hours. Further studies using *Gymnodinium catenatum* cysts have indicated that significant mortality can also be achieved using longer incubation times (several hours) at temperatures as low as 35°C to 37.5°C. This work needs to be repeated with *Alexandrium* cysts.

These findings, together with the likely temperature profiles that could be expected in tanks on the "Iron Whyalla", suggest that this mode of treatment could provide a cost effective and environmentally attractive treatment option for a range of phytoplankton species, including toxic dinoflagellate cysts. Studies are in progress to quantify the ballast water temperature profiles and to examine the feasibility of ocean trials, to assess some of the practical issues involved and to further evaluate this technique.

Receiving Port Conditions

One of the key issues in the overall scenario outlined in Figure 1 is the likelihood of a particular organism becoming established in the deballasting port. Several recent studies have now allowed some early conclusions to be drawn on this aspect. The likelihood of an introduced species becoming established, and creating a reproducing population, depends on many factors. These primarily include the ecological characteristics of the species and the environmental conditions into which it is inoculated. These characteristics determine whether the species will survive the voyage in the closed ballast tanks, and also whether it will establish viable populations within the deballasting port.

Species most likely to become established in a new environment are those which come from a similar hydrological environment (for example, species from temperate environments are more likely to survive in temperate estuaries than in tropical ones). Another important aspect is that of the receiving environment. Estuarine or shallow bay areas are more likely to provide conditions suitable for establishment of compatible species, whereas the strong ocean currents and high water velocities (coupled with inhospitable ocean bed conditions) existing in open offshore ports, will disperse the organisms much more widely than in the shallow estuarine areas, and provide conditions unsuitable for toxic dinoflagellate growth. Two recent case studies in the ports of Hay Point in Queensland, and Hobart in Tasmania (Australia) have highlighted some of these aspects[16].The port of Hay Point, located some 30 km south of Mackay in Queensland, is essentially a sub-tropical to tropical port with ocean temperatures varying between approximately 22°C and 27°C. The port has two coal export terminals (Hay Point and Dalrymple Bay) having a total export capacity in the vicinity of 50 Mtpa. The shipping berths are located 2 km offshore. Annual ballast water discharges from the bulk coal carriers are approximately 15 Mtpa. Tidal variations range from approximately 4m to 7m, and the ocean bottom, in and around the loading berths is essentially sandy to sandy/clay. Only minor amounts of mud (which would be conducive to retaining dinoflagellate cysts) exists in the port proper, although mud banks and other muddy areas exist to the north and to the south.

By contrast, the port of Hobart in Southern Tasmania, is essentially a temperate port with ocean temperatures varying from about 10°C to 18°C[17]. The shipping trade is essentially based on wood chips (Triabunna, since 1971), wood pulp (Port Huon, 1962-1982), fruit (Port Huon, 1950-1960), minerals (zinc) and general cargo (Hobart). Annual ballast water discharges amount to approximately 1Mtpa. Tidal variations range from 0.5 to 1.5m, and water movements (except during flooding) are relatively low (typically $50m^3s^{-1}$) compared to those which occur in the Port of Hay Point. Bottom conditions within the various bays and estuaries include predominantly fine mud conducive to retaining dinoflagellate cysts which may be discharged in ballast water and settle in the area.

A recent survey of the port of Hay Point unambiguously indicated the occurrence of a truly tropical plankton community with no evidence of the presence of toxic dinoflagellate species (such as *G. catenatum* and *Alexandrium*), both of which have been repeatedly detected in samples of ballast water discharged into this port[16,18,19].

The only dinoflagellate cysts detected (*Protoperidinium, Gonyaulax, Scrippsiella*) were of non toxic species, all of which are widespread through Australian waters.

However, in the Port of Hobart, the toxic dinoflagellate *Gymnodinium catenatum* is prolific, while both *G. catenatum* and *Alexandrium* cysts have also been detected in the neighbouring port of Triabunna.

These two case study examples clearly illustrate the significance of matching port conditions in relation to the establishment of toxic dinoflagellates. In the case of Hobart, the water temperatures (10°C to 18°C) are consistent with those in the majority of temperate Japanese ports, where the majority of ballast water originates (14°C to 21°C), whereas the temperatures in Hay Point (22°C to 27°C) are too high for establishment of the Japanese toxic dinoflagellates. Hallegraeff et al have shown that *Gymnodinium catenatum* blooms in Tasmania tend to proliferate at water temperatures in the range of 12°C to 18°C[20]. In addition to the temperature match between Hobart and the Japanese ports, the local environmental conditions (relatively low water movement and abundance of muddy bottom areas) also provide a desirable substrate for retention, and subsequent establishment of dinoflagellate cysts.

The initial Australian focus on toxic dinoflagellates, has allowed significant progress to be made in developing an overall strategy, and assessing a range of treatment/management options which may ultimately become part of the "tool kit" for implementation during the voyage.

The range of "target" organisms is currently under review by the Australian Ballast Water Advisory Council and the Research Advisory Committee. Further research projects aimed at establishing the extent of organism invasion, developing a risk management system and investigation of further treatment options for the "target" species" are also being developed.

A range of other management options, incorporating selective port ballasting, containment of contaminated water, utilisation of alternative sources of water, and ship design changes to allow more widespread and safe use of many of the potential options, are possible for future long term consideration and implementation.

Ongoing collaboration, at the international level is considered to be essential, to minimise duplication of efforts and to exchange the results of observation and research investigations.

CONCLUSION

It can be seen that by developing international and national management strategies involving an understanding of ballasting and receiving port conditions, and the behaviour of organisms in ballast tanks, coupled with a range of en-route management and treatment options, the impact of ballast water discharges can be effectively managed.

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