Mid Ocean Ballast Water Exchange: Shipboard Trials of Methods for Verifying Efficiency

Prepared for

Ministry of Fisheries

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Cover Photo: View from the bridge of the M.T. *Iver Stream*

EXECUTIVE SUMMARY

Voyages on a coastal container vessel (M.V. *Spirit of Vision*) and a trans-Pacific chemical carrier (M.T. *Iver Stream*), were used to test methodologies for assessing:

- the dilution efficiency of mid-ocean exchange;
- whether international shipping has complied with mandatory controls and voluntary mid-ocean ballast water guidelines;
- and the efficacy of mid-ocean exchange at expelling those organisms (especially unwanted organisms) that were resident in the ballast tanks before the exchange.

The study established that the tracer dye Rhodamine WT is particularly useful for measuring the dilution efficiency of mid-ocean ballast water exchanges, including the possible retention of the original ballast water in parts of the tank during the exchange. In each of the mid-ocean ballast water exchange trials, all of which used the flow-through dilution method, the dilution efficiency of the completed exchange (i.e. after three times the tank volume had been pumped through the tank) was in excess of 90% (*Spirit of Vision*; tank capacity = 114 m^3) or 99% (*Iver Stream*; tank capacity = 1435 m^3).

Selective use of tracer dyes by adding the dye prior to refilling the ballast tanks, may have application in calibrating indirect measures of dilution (e.g. the use of optical signatures – see below), or standardising the dilution efficiency of tanks with different configurations. This would enable implementation of mid-ocean exchange compliance requirements for different classes of vessels. Given the logistical constraints of having to add the tracer dye to the tank before the exchange, however, it is unlikely that tracer dyes will be useful as practical compliance tools for routinely verifying that a mid-ocean exchange has taken place. The usefulness of salinity as a tool for verifying mid-ocean exchange is restricted to the detection of source port water that is relatively low in salinity (i.e. brackish or freshwater).

To verify whether or not a ship has exchanged its ballast water in mid-ocean, it is necessary to find a characteristic of the water that is distinct for different water types and can be readily measured. DOM (dissolved organic matter) UV fluorescence, expressed as high resolution EEM (excitation emission matrix) spectra, shows definite potential as a tool for discriminating between coastal and mid-ocean water. EEM is a relatively simple and straightforward measurement which can be used as a tool for discriminating between water types. The study has helped in identifying the regions of the spectrum that are most useful in discriminating between coastal and mid-ocean water.

The EEM spectra derived from samples collected during the project demonstrated a clear difference between the optical characteristics of ballast water collected before and after mid-ocean exchange. After each exchange, the optical signatures shifted from signatures typical of the coastal water at the source ports, to those typical of the mid-ocean water during the exchange. The shifts were concomitant with a marked reduction in the concentration of the tracer dye. A shift in the optical signatures was not observed in the control (non-exchanged) tank.

The work has also shown relative consistency in the optical signatures of mid-ocean water, which suggests that there is a very limited presence of DOM fluorophores in mid-ocean. We

have also identified strong humic-like and protein-like signatures in the EEMs of coastal water and in the ballast water taken up by the ship in port. The similarity in the EEMs of ballast water samples collected after mid-ocean exchange and the EEMs of samples collected from the mid-ocean during the exchange, demonstrated that there was no significant source of fluorescence contamination within the ballast tanks themselves. Hence, the development of fluorescence based technologies as a tool for verifying mid-ocean ballast water exchange has great potential. In addition, the study has demonstrated the potential for using *in situ* instrumentation for measuring fluorescence intensity, however further research is required to further develop the technique.

The trials on the *Spirit of Vision* provided evidence for the retention of phyto- and zooplankton uplifted from the source port when using the flow-through dilution method of mid-ocean exchange. On the other hand, the trials on the *Iver Stream* indicated that the flow-through dilution method can be relatively effective at reducing the number of planktonic organisms previously uplifted in the source port. A 90-100% reduction in the means of depth-stratified counts of source port indicator taxa was achieved. An important consideration on the *Iver Stream* voyage, however, was variable rates in the survivorship of indicator taxa in the control (non-exchanged) ballast tank during mid-ocean exchanges. Survivorship was reduced considerably after five days from loading the tank, and mortality was consistent with a warming (14-26°C) of the tank as the vessel travelled from Japan to the tropics. The decline in the abundance of indicator taxa after mid-ocean exchanges of the test tanks, contrasted with a less effective reduction in the total number of source port taxa; i.e., 54-58%.

Although it is recommended that ships exchange their ballast water in depths of at least 2000 m, greater emphasis should be placed on whether the water uplifted in mid-ocean is, in fact, sufficiently oceanic (i.e. without coastal organisms). On some shipping routes (e.g. Japan to New Zealand via Singapore), mid-ocean exchanges are likely to be carried out in shallower (i.e. < 2000 m) waters near the influence of large rivers. Such exchanges increase the potential to replenish the ballast tank with unwanted organisms, and salinity differentials may influence the dilution efficiency and the effectiveness of the exchange at expelling the original organisms in the ballast tank.

Ballast tanks are heterogeneous environments (e.g. top of the water column versus the bottom sediments), and there are complex interactions between the mixing dynamics of the existing water and sediments, the incoming water during exchanges, and between the water and the organisms themselves. This complexity is further increased by variation in the physical, physiological and behavioural tolerances of the different groups of ballast water organisms.

In the light of this research, it is recommended that biological indicators of the efficacy of mid-ocean exchanges should include assessment of:

- the changes in species composition and abundance of planktonic assemblages and sediment-dwelling organisms brought about by the exchange;
- the incidence of coastal versus oceanic and cold versus warm water species found in ballast tanks, and taxa that are known to be relatively tolerant of such environments (e.g. dinoflagellate cysts);
- relative abundance of viable phytoplankton communities, which may be indicative of recent mid-ocean exchanges;
- the presence of target organisms (e.g. *Asterias amurensis*).

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