Ballast Water Risk Assessment: The Indian Experience

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ABSTRACT The Ballast Water Risk Assessment serves as a “Decision Support System” for any given port to take appropriate ballast water management actions. Risk assessment involves collation of data from the ballast water reporting forms to identify the source of ballast water. The environmental characteristics of the source and recipient ports are utilized to evaluate the similarities. This is then combined with other risk factors, including voyage duration and risk species to gain a preliminary indication of the overall risk posed by each source port. The results will help in evaluating the risk posed by ballast water introductions, and decide whether to apply a blanket or selective ballast water management regime. The experience in India with ballast water risk assessment showed that manually submitted ballast water reporting forms were ridden with inaccuracies. Hence, self-validating electronic ballast water reporting forms (e-BWRF) were introduced to overcome such inaccuracies. Our experience with the risk assessment conducted in an Indian port Visakhapatnam, suggests that the local ports pose higher risk of introduction. However, under such circumstances a risk reduction factor was introduced in the method to counter geographical proximities. The paper provides an overview of lessons learnt through ballast water risk assessment in India and the necessary corrective actions taken thereof.

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1. INTRODUCTION

Risk assessment is a fundamental starting point in the implementation of a formal system to manage the transfer and introduction of harmful aquatic organisms and pathogens by ships' Ballast Water. It serves as a Decision Support System (DSS) for the concerned authorities, especially the Port State, to take appropriate action towards achieving better environmental protection against shipping activities without hampering the sea trade.

The first step of risk assessment involves collation of data from IMO Ballast Water Reporting Forms (BWRF) to identify the source ports from which Ballast Water is imported to the destination/recipient port. Thereafter a range of environmental data is collated from both source and the destination/recipient ports for comparison. These data are then combined with other risk factors, including voyage duration and risk species profiles, to give a preliminary indication of overall risk posed by each source port to the recipient port. The results provide a knowledge base that will help the respective port state or port to evaluate the risks currently posed by BW introductions, identify high priority areas for action, and decide whether to apply a blanket or selective BW management regime. If a selective regime is adopted, vessel and voyage-specific risk assessment can then be applied. If a uniform approach is adopted, the results help to identify which routes and vessel types warrant the most vigilance in terms of BW management compliance checking and verification monitoring, including ship inspections and ballast tank sampling (Anil et al. 2003).

The experience in India with ballast water risk assessment showed that manually submitted ballast water reporting forms were ridden with inaccuracies, requiring intervention. Self-validating electronic ballast water reporting forms (e-BWRF; details available at www.bwmindia.com) could overcome such inaccuracies. Our experience gained through risk assessment conducted in an Indian port pointed out a high degree of environmental similarity between local ports that would put them at higher risk. However, under such circumstances a risk reduction factor to counter geographical proximities was introduced in the method to arrive at the risk that would be associated with ballast water mediated translocation of organisms. The paper provides an overview of lessons learnt through ballast water risk assessment conducted in Visakhapatnam Port situated on the east coast of India and the necessary corrective actions taken thereof.

2. MATERIALS AND METHODS

The methodology and its related description in the present case have been adopted/reproduced from the GloBallast Monograph Series No. 11 (Anil et al. 2003) with some modification (as elaborated in results section). Ballast water Risk Assessment was conducted by adopting an innovative, modular approach that integrated three widely used computer software packages to provide a user-friendly tool. The schematic of which is shown in Figure 1.

- Microsoft Access – for the main database,
- PRIMER 5 (Plymouth Routines in Marine

Figure 1. Flow chart of Ballast Water Risk Assessment System (see also Anil et al., 2003)

Environmental Research) – a versatile multivariate analysis package from the United Kingdom enabling convenient multivariate analysis of the port environmental data.

- ESRI Arc View 3.2 Geographic Information System (GIS) to graphically display the results in a convenient, readily interpretable format using port and world maps.

Initially, the BWRFs submitted by the arriving ships to Visakhapatnam port from overseas and India were scrutinized for correct entries. Data from validated forms were then entered into the customized Access database, which identifies source and destination ports as well as perform the BWRA. Simultaneously, data pertaining to port environment and risk species were collated from published literature and websites (Rama Raju et al. 1987; <http://www.worldclimate.co>; <http://www.jodc.go.jp/>; <http://www.ncdc.noaa.gov/oa/ncdc.html>; Hilliard et al. 1997a,b; <http://globallast.org>; <http://www.env.go.jp/en/nature/as.html>; <http://www.issg.org/>). Thirty four environmental variables were collated for Visakhapatnam port as well and its source ports, which included seawater and air temperature, salinity, seasonal rainfall, tidal regimes and proximity to a standardized set of intertidal and sub-tidal habitats.

Multivariate analysis of the port environmental data was undertaken using the PRIMER package, with the similarity values between Visakhapatnam port and its source and destination ports converted into environmental matching coefficients, which were then added to the database. Species in or near source ports that were deemed to pose a threat if introduced to these ports, were identified from all available sources, including port biological baseline surveys. Taxonomic information and biogeographical distributions of marine species were also added to the Access database. The combined BW discharge, environmental matching and risk species coefficients provided the basis of the semi-quantitative risk assessment. Graphic User Interface (GUI) customized for the Access database and ArcView GIS were used to visualize results, tables and graphical outputs that were displayed on interactive maps of the Visakhapatnam port

area and world bioregions.

To provide a measure of the risk species threat posed by each source port, the algorithm analyzed the status of each species assigned to each bioregion and generated a set of coefficients, which was then used to calculate relative overall risk. Each species was assigned to one of three levels of threat, with each level weighted on a logarithmic scale as follows:

- Lowest threat level: This was assigned to species with no special status other than their reported or strongly suspected introduction by BW and/ or hull fouling in at least one bioregion (i.e., population/s with demonstrated genetic ability to survive, transfer and establish in regions beyond their native range). A fixed weighting (1) is applied to each of these species when present in bioregions outside their native range. This was also the default level assigned to any species when first added to the database.
- Intermediate threat level: This level was assigned to any species suspected to be a harmful species or invasive pest. Risk species assigned to this level received a default weighting value of 3 in both their native and introduced bioregions.
- Highest threat level: This level was assigned to known harmful invasive species, as reported in institutional or government lists of aquatic nuisance species and pests, and/ or in peer-reviewed scientific journals. The default weighting value applied to these species was 10.

The database calculated the coefficient of 'risk species threat' posed by each source port, with each port value representing a proportion of the total risk species threat. The latter was the sum of all weighted risk species assigned to the bioregion of all source ports that export BW to the destination port.

The risk species coefficient for each source port was therefore calculated by firstly summing the number of non-indigenous species (NIS) in the port's bioregion that have no suspected or known harmful status. This provided a measure of low level 'weedy' and sometimes cosmopolitan species which, although having no

acknowledged harmful status, have proven transfer credentials that could enable their establishment in another port. While the probability of their establishment is low, they nevertheless may possess unpredictable biological or economic consequences. This number was then added to the sums of suspected and known harmful species in the same bioregion, if any. The default calculation for the risk species coefficient for each source port (C) is thus:

$$C_{\text{sourceport}} = \frac{(\text{NIS} + [\text{Suspected Harmful} \times 3] + [\text{Known Harmful} \times 10])}{\text{Total Sum of all Source ports}}$$

The C values lie between 0-1 and represent an objective measure of the relative total species threat.

2.1 Risk coefficients and risk reduction factors

For each source port, the database used four coefficients of risk (C1-C4) and two risk reduction factors (R1, R2) to produce a relative overall measure of the risk of a harmful species introduction at the Visakhapatnam port.

C1 – proportion of the total number of ballast tank discharges made at the destination port

C2 – proportion of the total volume of BW discharged at the destination port.

C3 – port-to-port environmental similarity, as expressed by the matching coefficient,

C4 – source port's contribution to the total risk species threat to the destination port, as posed by the contemporary pattern of trade.

In biological terms, C1 and C2 represent the frequency and size of organism 'inoculations' respectively. C3 provides a measure of the likely survivability of these inoculated organisms and C4 the relative threat posed by the organisms within each inoculation. Each coefficient has values between 0-1 except C3, where the lowest value was set to 0.01 (it is unsafe to assume a port environment can be sufficiently hostile to prevent survival/establishment of every transferred introduced species).

The two risk reduction factors calculated by the database were R1 (effect of ballast tank size on C2) and R2 (effect of tank storage time on C4). R1 represents the effect of tank size on the number and viability of organisms that survive the voyage, since water quality typically deteriorates more rapidly in small tanks than large tanks (owing to the volume/tank wall ratio and other effects such as more rapid temperature change, with mortality rates generally higher in small tanks). As described below, no risk reduction was applied to any source port dispatching vessels with tank volumes greater than 1000 tonnes.

R2 represents the effect of tank storage time on the range and viability of discharged organisms. Survival of most phytoplankton and aerobic biota inside any tank decreases with time, with relatively high survival rates reported for voyages less than five days (as shown below, this was adopted as the cut-off point for any risk reduction due to in-tank mortality).

The database calculates the tank storage time by subtracting the reported tank discharge date from the ballast uptake date. For incomplete BWRFs with missing discharge or uptake dates, the vessel arrival date plus standard voyage duration at 14 knots were used to estimate the BW uptake date for adding to the database.

The database automatically provides values for R1 and R2 using a log rhythmic approach.

R1Maximum tank volume discharged (tonnes) in the database record for each source port	<100	100-500	500-1000	>1000	
W4 Default risk-reduction weighting applied to C2	0.4	0.6	0.8	1	
R2Minimum tank storage time (days) in the database record for each source port	<5	5-10	10-20	20-50	>50
W5 Default risk-reduction weighting applied to C4	1	0.8	0.6	0.4	0.2

The relative overall risk (ROR) can be calculated by using the following equation and expressed as a ratio over a scale of 0-1 or percentage of the total risk posed by the source ports.

$$\text{ROR} = (C1 + [C2 \times R1_{w4}] + C3 + [C4 \times R2_{w5}]) / 4$$

3. RESULTS AND DISCUSSION

Initially, for the period from 2002 to 2008, a total of 1925 paper forms (BWRFs) were received from Visakhapatnam harbour, situated on the east coast of India. Of these, only 454 forms were found valid and the rest (1471) were considered as invalid (76%) due to various errors.

In order to overcome this problem, an e-Form, which is self-validating, and user-friendly, was developed (see www.bwmindia.com). As a result, 404 error free e-BWRFs, were received from ships and imported into the database.

The database calculated the relative overall risk (ROR) of a potentially harmful introduction for all source ports that had C1-C4 coefficients and R1-R2 factors. The ROR value for each source port represented a proportion of the threat posed to the Visakhapatnam harbour as a result of its contemporary trading pattern during the period 2002-2008.

After calculating the RORs, the database generated a large output table listing the source ports and their coefficients, risk-reduction factors and ROR values, including the five ROR categories used for the GIS plot and the standardised ROR values (S-ROR). From the 858 visit records in the Visakhapatnam database, the BWRA output identified 12 (13%) of the 92 identified source ports as representing the highest risk group, in terms of their BW source frequency, volume, voyage duration, environmental similarity and assigned risk species. The highest risk ports were Tuticorin (ROR= 0.38; S-ROR=1.00) and Kaohsiung (ROR= 0.36; S-ROR= 0.95) in India and Taiwan respectively, followed by Hong Kong (ROR= 0.36; S-ROR=0.94) and Taichung, Taiwan (ROR= 0.35; S-ROR= 0.89)) being third and fourth in the ranking respectively. Of the total number of highest ranked ports, Japan shared the maximum number (6) followed by Taiwan (2). The others were one each from India, Hong Kong, China and Korea. In general, the 91.6% of the highest ranked ports were non-Indian, suggesting possible risk of introduction from these ports.

The next risk category (High Risk) enlists 15 source ports with ROR ranging from 0.29 to 0.32 and the S-ROR from 0.68 to 0.78. Of these, the overseas ports dominated the number with 73%, followed by Indian ports with 27% (Table 1).

The 46 source ports in the medium (16), Low (22) and Lowest (28) risk categories were a mixture of environmentally dissimilar, no known risk species and/or less trading ports (Table 2).

Table 1. BW source ports reported for Visakhapatnam ranked according to their Relative Overall Risk (ROR), prior to applying distance factor.

Port Code	Source Port	Country	C1	C2	Max Tank Disch (MT)	R1	Min Tank Stor (d)	R2	C3	C4	ROR	% of Toatl Risk	Cumu %	Risk Catogor.	S-ROR
INTUT	Tuticorin	India	0.16	0.16	34018	1	0	1	0.670	0.522	0.38	1.75	1.75	Highest	1.00
TWKHH	Kaohsiung	Taiwan	0.00	0.00	13818	1	4	1	0.559	0.894	0.36	1.68	3.44	Highest	0.95
HKHKG	Hong Kong	Hong Kong	0.01	0.01	38028	1	0	1	0.535	0.894	0.36	1.68	5.12	Highest	0.94
TWTXG	Taichung	Taiwan	0.01	0.02	30000	1	1	1	0.435	0.933	0.35	1.61	6.73	Highest	0.89
JPKMT	Kimitsu Chiba	Japan	0.00	0.00	1258	1	1	1	0.449	0.922	0.34	1.59	8.31	Highest	0.87
JPNGO	Nagoya Aichi	Japan	0.00	0.00	5859	1	2	1	0.445	0.922	0.34	1.58	9.89	Highest	0.87
JPKWS	Kawasaki Kanagawa	Japan	0.00	0.00	3544	1	4	1	0.442	0.922	0.34	1.58	11.48	Highest	0.87
JPFKY	Fukuyama Hiroshima	Japan	0.00	0.00	2780	1	3	1	0.441	0.922	0.34	1.58	13.06	Highest	0.87
JKOK	Kokura (Kitakyushu) Fukuoka	Japan	0.00	0.00	624	0.8	1	1	0.416	0.933	0.34	1.56	14.62	Highest	0.85
JPMIZ	Mizushima Okayama	Japan	0.01	0.02	26630	1	0	1	0.392	0.922	0.34	1.55	16.16	Highest	0.84
CNXMN	Xiamen (Weitou) Fujian	China	0.00	0.00	8514	1	0	1	0.395	0.933	0.33	1.54	17.70	Highest	0.83
KRMAS	Masan	Korea	0.00	0.00	2807	1	3	1	0.351	0.933	0.32	1.48	19.19	Highest	0.79
KRONS	Onsan	Korea	0.00	0.00	334	0.6	3	1	0.356	0.911	0.32	1.46	20.65	High	0.78
INMAA	Chennai	India	0.08	0.09	20249	1	-7275	1	0.566	0.522	0.32	1.46	22.10	High	0.77
INPRT	Paradeep	India	0.06	0.06	16623	1	0	1	0.586	0.522	0.31	1.41	23.52	High	0.74
CNTSN	Tianjin Tianjin	China	0.00	0.00	409	0.6	3	1	0.277	0.933	0.30	1.40	24.92	High	0.73
CNTXG	Tianjinxingang (Xingang) Tianjin	China	0.00	0.00	9350	1	4	1	0.287	0.911	0.30	1.39	26.31	High	0.72
JPHHR	Higashi Harima Hyogo	Japan	0.00	0.00	2009	1	6	0.8	0.461	0.922	0.30	1.39	27.70	High	0.72
INVTZ	Visakhapatnam	India	0.06	0.05	19855	1	0	1	0.568	0.522	0.30	1.38	29.08	High	0.71
CNZJG	Zhangjiagang (Changjiagang) Jiangsu	China	0.00	0.00	22	0.4	0	1	0.258	0.933	0.30	1.38	30.46	High	0.71
CNNTG	Nantong Jiangsu	China	0.00	0.00	3990	1	2	1	0.255	0.933	0.30	1.37	31.83	High	0.71
JPCHB	Chiba Chiba	Japan	0.00	0.00	3304	1	6	0.8	0.449	0.922	0.30	1.37	33.20	High	0.70
CNMWN	Mawan Guangdong	China	0.00	0.00	3348	1	3	1	0.285	0.894	0.30	1.36	34.57	High	0.70
CNFAN	Fangcheng (Qinzhou) Guangxi	China	0.00	0.00	0	0.4	0	1	0.287	0.894	0.30	1.36	35.93	High	0.70
CNHUA	Huangpu (Xinzao) Guangdong	China	0.00	0.00	1391	1	3	1	0.285	0.894	0.30	1.36	37.29	High	0.70

Based on Visakhapatnam's current pattern of trade (as implied by the 2002-2008 records), the results suggested that BW from vessels arriving from Japan and Taiwan posed a greater threat, in terms of risk species introduction, than any other trading overseas ports. The risk posed by the Indian ports is also considerable, as observed from list of Highest and High-risk categories.

Table 1 also indicated that a good number of Indian ports presented Highest and High risks to Visakhapatnam harbour. Local 'port-hopping' may facilitate invasion by harmful species, if present in those ports, to the Visakhapatnam environment. The presence of the East Asian green lipped mussel (*Perna viridis*) and the Caribbean black-striped mussel (*Mytilopsis sallei*) in Mumbai harbour support this conclusion. In the case of *Mytilopsis sallei*, this nuisance fouling mussel is believed to have 'port-hopped' to Mumbai from its earlier establishment in Visakhapatnam. The latter is a major port on India's east coast that has more frequent vessel arrivals from Atlantic ports than Mumbai. However, logically the ports within the same bioregion and subjected to natural dispersion and/or having no harmful

invasive species, cannot be considered as posing much risk. In view of this, the risk calculation (coefficient) warrants appropriate review.

The risk output results suggest that some local ports (source ports) fall under highest (1 port) and high (4 ports) risk categories. Of these, some are very close and lie within a radius of <500 km. Logically such local ports are less likely to pose high risk to the destination port, due to similarity in the environment and the biology. This is one of the criteria adopted for demarcating world bioregions, which represents environmentally similar geographic areas. Thus, if a species is found established in one port of a bioregion, there is a good chance that it can spread via natural or human-mediated processes to other sites in the same bioregion. A conservative approach was therefore adopted in this study, whereby a risk species if recorded in at least one location of a bioregion, is assumed potentially present or will spread naturally at all source ports within the same bioregion.

In view of this, necessary reduction/distance factor was applied to the Risk coefficient, so as to reduce the Overall Risk to the destination port from its local source

Table 2. Ballast water source ports identified for Visakhapatnam port ranked according to their revised Relative Overall Risk (ROR). See also Figure 2.

Port Code	Source Port	Country	Initial ROR	Distance based Reduct.Factor	Revised ROR	% of Total Risk	Cumul. %	Risk Category	Revised S-ROR
INTUT	Tuticorin	India	0.38	1	0.38	1.86	1.9	Highest	1.00
TWKHH	Kaohsiung	Taiwan	0.36	1	0.36	1.78	3.6	Highest	0.95
HKHKG	Hong Kong	Hong Kong	0.36	1	0.36	1.78	5.4	Highest	0.95
TWTXG	Taichung	Taiwan	0.35	1	0.35	1.71	7.1	Highest	0.90
JPKMT	Kimitsu Chiba	Japan	0.34	1	0.34	1.68	8.8	Highest	0.88
JPNGO	Nagoya Aichi	Japan	0.34	1	0.34	1.68	10.5	Highest	0.88
JPKWS	Kawasaki Kanagawa	Japan	0.34	1	0.34	1.68	12.2	Highest	0.88
JPFKY	Fukuyama Hiroshima	Japan	0.34	1	0.34	1.67	13.8	Highest	0.88
JPKOK	Kokura (Kitakyushu) Fukuoka	Japan	0.34	1	0.34	1.65	15.5	Highest	0.86
JPMIZ	Mizushima Okayama	Japan	0.34	1	0.34	1.64	17.1	Highest	0.86
CNXMN	Xiamen (Weitou) Fujian	China	0.33	1	0.33	1.63	18.8	Highest	0.85
KRMAS	Masan	Korea	0.32	1	0.32	1.57	20.3	High	0.81
KRONs	Onsan	Korea	0.32	1	0.32	1.55	21.9	High	0.80
CNTSN	Tianjin Tianjin	China	0.30	1	0.30	1.48	23.4	High	0.75
CNTXG	Tianjinxingang (Xingang) Tianjin	China	0.30	1	0.30	1.48	24.8	High	0.75
JPHHR	Higashiharima Hyogo	Japan	0.30	1	0.30	1.47	26.3	High	0.74
CNZJG	Zhangjiagang (Changjiagang) Jiangsu	China	0.30	1	0.30	1.46	27.8	High	0.74
CNNTG	Nantong Jiangsu	China	0.30	1	0.30	1.45	29.2	High	0.73
JPCHB	Chiba Chiba	Japan	0.30	1	0.30	1.45	30.7	High	0.73
CNMWN	Mawan Guangdong	China	0.30	1	0.30	1.45	32.1	High	0.73
CNFAN	Fangcheng (Qinzhou) Guangxi	China	0.30	1	0.30	1.44	33.6	High	0.73
CNHUA	Huangpu (Xinzao) Guangdong	China	0.30	1	0.30	1.44	35.0	High	0.73
CNZUH	Zhuhai Guangdong	China	0.30	1	0.30	1.44	36.4	High	0.73
CNSHK	Shekou Guangdong	China	0.29	1	0.29	1.42	37.9	High	0.71
CNRZH	Rizhao (Shijiu) Shandong	China	0.28	1	0.28	1.36	39.2	High	0.67

ports. Following criteria were adopted for assigning reduction factors.

- Any port lying at a distance of ≤ 100 km was given a default value of 0.1.
- The port at a distance of ≤ 500 km was assigned default values of 0.3.
- The source port situated at a distance of ≤ 1000 km was given default reduction factor of 0.5.
- On the other hand, port lying beyond 1000 km, was given a default value of 1.

The results of risk analyses for Visakhapatnam port, after applying the above reduction factors, are presented in Table 2. The revised table shows that 11 source ports are in the Highest risk category, followed by another 14 ports in the High risk category. The Medium, Low and Lowest categories comprised 17, 21 and 29 ports

respectively. Tuticorin, a lone Indian port, stands first in the list of highest risk category (ROR= 0.38; S-ROR= 1.0) followed by Kaohsiung (ROR= 0.36; S-ROR= 0.95), Hong Kong (ROR= 0.36; S-ROR=0.95) and Taichung (ROR= 0.35; S-ROR= 0.90)) from Taiwan, Hong Kong and Taiwan being second, third and fourth in the ranking respectively. Of the total number of highest ranked ports, Japan shared the maximum number (6) followed by Taiwan (2). The others were one each from India, Hong Kong and China. In general, 91% of the highest ranked ports were non-Indian, suggesting possible risk of introduction from these ports, especially Japan.

The next risk category (High Risk) enlists 14 source ports with ROR ranging from 0.28 to 0.32 and the S-ROR from 0.67 to 0.81. These categories comprised of all overseas ports, of which 71% were in China (Table 2).

The rest of the 67 source ports were categorized as Medium (17), Low (21), and Lowest (29) risk, which could be

Figure 2. GIS outputs showing the location and categories of revised relative overall risk (ROR) of source ports identified for Visakhapatnam.

a mixture of environmentally dissimilar, no risk species threat or less trading ports. Fig.2 shows the spatial distribution of the ports with different S-ROR values.

Based on Visakhapatnam's current pattern of trade (as implied by the 2002-2008 records), the results suggest that BW from vessels arriving from Japan and Taiwan pose greater threat than any other overseas trading ports.

These results, even after applying a distance-based reduction factor, also suggests a lone Indian port, Tuticorin, located on the east coast of India, posed the highest risk to Visakhapatnam port. This is because of the higher values of risk coefficients C1, C2 and C3 (Table. 1). Therefore, the formula used for calculating ROR needs to be reviewed further so as to avoid local ports appearing as risky ports.

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