## Vessel Type Biosecurity Risk Framework: Supplementary Material

Mimi W. Tzeng, Oliver Floerl, Anastasija Zaiko

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Table S1. Kendall rank correlation results for risk factors with multiple data sources.

| **Risk Factor** | **Data Source 1** | **Data Source 2** | **Tau estimate** | **P value** |
| --- | --- | --- | --- | --- |
| Average WSA | Moser et al. (2016) | Davidson et al. (2006) | 0.2 | 0.817 |
| Average WSA | Moser et al. (2016) | Inglis et al. (2010) | 0.414 | 0.251 |
| Average WSA | Davidson et al. (2006) | Inglis et al. (2010) | -0.276 | 0.444 |
| Port Duration | Davidson et al. (2018) | Inglis et al. (2010) | 0.828 | 0.022 |
| Typical Speed | Davidson et al. (2018) | Inglis et al. (2010) | 0.414 | 0.251 |
| Ballast Discharge Volume | Davidson et al. (2018) | CEBRA (2019) | 0.867 | 0.017 |
| Ballast Discharge Frequency | Davidson et al. (2018) | CEBRA (2019) | 0.414 | 0.251 |

Table S2. Confidence ranks were assigned to data values selected for each combination of vessel type and risk factor, based on number of vessels, whether the vessel type was in combination with other vessel types in the source study, and whether data values were copied from a proxy vessel type. 1 = highest confidence, 4 = lowest confidence.

| **risk factor** | **GEN** | **BLK** | **TNK** | **CON** | **RRO** | **RFR** | **LQG** | **HVY** | **PSS** | **LSC** | **FSN** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Hull WSA | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 2 | 1 |
| Complexity of hull WSA | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 1 |
| port duration | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 1 | 2 | 3 |
| typical speed | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 1 | 2 | 3 |
| amount of biofouling | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 4 | 3 |
| ballast water capacity | 2 | 1 | 1 | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 4 |
| ballast discharge volume | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 3 | 3 |
| ballast discharge frequency | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 3 |

Table S3. Maximum ballast tank capacity (mt) compared to gross tonnage (GT) for seven vessel types considered in this study. Data are from the National Ballast Information Clearinghouse (NBIC) for 4260 vessels that visited the United States in 2014. Proportion of ballast tank capacity to gross tonnage (BCPT) was calculated by dividing ballast tank capacity by GT for each vessel. Mean ballast capacity data (highlighted) were used in the risk quantification framework (see Tables 3 and 4 of main text).

|  | **Passenger (PSS)** | **Bulker (BLK)** | **Container (CON)** | **RoRo (RRO)** | **Tanker (TNK)** | **General Cargo (GEN)** | **Reefer (RFR)** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Min Tonnage** | 761 | 642 | 2899 | 194 | 182 | 211 | 483 |
| **Max Tonnage** | 1185920 | 1134492 | 68739941 | 1162080 | 46511147 | 39258 | 6714413 |
| **Mean Tonnage** | 92579.61 | 31989.61 | 181206.7 | 54697.12 | 78586.64 | 14280.92 | 84819.75 |
| **SD Tonnage** | 106212.5 | 46050.08 | 2853833 | 78254.78 | 1235428 | 10329.13 | 699503.8 |
| **Min Ballast Capacity** | 17 | 131 | 1487 | 45 | 0 | 1 | 129 |
| **Max Ballast Capacity** | 12105 | 80089 | 46572 | 17767 | 109135 | 30921 | 4064 |
| **Mean Ballast Capacity** | 3673.896 | 23093.32 | 16661.01 | 7651.942 | 29227.15 | 7694.073 | 1219.63 |
| **SD Ballast Capacity** | 2568.861 | 11221.36 | 8127.488 | 2821.194 | 22930.52 | 5853.926 | 908.483 |
| **Min BCPT** | 0.003396 | 0.014341 | 0.00017 | 0.008663 | 0 | 0.004739 | 0.000437 |
| **Max BCPT** | 0.189291 | 1.818841 | 0.739565 | 1.062303 | 1.800171 | 1.573073 | 0.461698 |
| **Mean BCPT** | 0.046652 | 0.761095 | 0.336779 | 0.185878 | 0.692691 | 0.534979 | 0.127331 |
| **SD BCPT** | 0.025593 | 0.221861 | 0.094871 | 0.129699 | 0.13686 | 0.121338 | 0.067535 |
| **Number of Vessels** | 134 | 1308 | 580 | 344 | 1421 | 381 | 92 |

Table S4. Results of post-hoc pairwise Dunn tests with Bonferroni adjustments on BCPT. The Kruskal-Wallis test result was: chi-squared = 2637.6, df = 6, p-value < 2.2e-16. The BCPT varied significantly between all combinations of vessel types with the exception of comparisons among PSS, RFR, and RRO (highlighted rows).

| **Comparison** | **Z** | **P.adj** |
| --- | --- | --- |
| BLK - CON | 32.654837 | 1.44E-232 |
| BLK - GEN | 16.734769 | 1.54E-61 |
| CON - GEN | -9.929272 | 6.52E-22 |
| BLK - PSS | 25.286137 | 9.53E-140 |
| CON - PSS | 6.93304 | 8.65E-11 |
| GEN - PSS | 13.135832 | 4.31E-38 |
| BLK - RFR | 19.719087 | 3.11E-85 |
| CON - RFR | 4.436695 | 1.92E-04 |
| GEN - RFR | 9.922844 | 6.95E-22 |
| PSS - RFR | -1.230637 | 1.00E+00 |
| BLK - RRO | 32.29107 | 1.96E-227 |
| CON - RRO | 4.813572 | 3.11E-05 |
| GEN - RRO | 13.208265 | 1.65E-38 |
| PSS - RRO | -3.308826 | 1.97E-02 |
| RFR - RRO | -1.451084 | 1.00E+00 |
| BLK - TNK | 4.204768 | 5.49E-04 |
| CON - TNK | -29.791294 | 1.06E-193 |
| GEN - TNK | -14.09421 | 8.66E-44 |
| PSS - TNK | -23.597185 | 8.65E-122 |
| RFR - TNK | -18.273149 | 2.84E-73 |
| RRO - TNK | -29.880482 | 7.41E-195 |

Table S5. Application of risk quantifications from the vessel biosecurity risk framework to derive relative risk at various ports of New Zealand, based on shipping traffic in 2015 and 2016.

| **Arrival Port** | **Vessel Visits 2015** | **Vessel Visits 2016** | **Vessel Visits Mean** | **Port Risk 2015** | **Port Risk 2016** | **Port Risk Mean** | **Allocation** | **Port Risk: Biofouling Proportion** | **Port Risk: Ballast Water Proportion** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Auckland | 1235 | 1231 | 1233 | 7152.09 | 7166.67 | 7159.38 | 0.17 | 0.68 | 0.32 |
| Bluff | 208 | 213 | 210.5 | 1919.16 | 1971.39 | 1945.275 | 0.05 | 0.46 | 0.54 |
| Gisborne | 91 | 128 | 109.5 | 947.04 | 1355.52 | 1151.28 | 0.03 | 0.42 | 0.58 |
| Lyttelton / Christchurch | 605 | 639 | 622 | 4126.26 | 4489.23 | 4307.745 | 0.10 | 0.58 | 0.42 |
| Napier | 543 | 603 | 573 | 3497.7 | 4043.4 | 3770.55 | 0.09 | 0.60 | 0.40 |
| Nelson | 281 | 301 | 291 | 1769.34 | 2017.38 | 1893.36 | 0.04 | 0.62 | 0.38 |
| New Plymouth | 225 | 230 | 227.5 | 2276.46 | 2327.82 | 2302.14 | 0.05 | 0.45 | 0.55 |
| Picton | 72 | 73 | 72.5 | 595.74 | 613.53 | 604.635 | 0.01 | 0.50 | 0.50 |
| Port Chalmers / Dunedin | 379 | 390 | 384.5 | 2573.94 | 2709.12 | 2641.53 | 0.06 | 0.59 | 0.41 |
| Tauranga | 1260 | 1295 | 1277.5 | 8899.83 | 9356.76 | 9128.295 | 0.21 | 0.56 | 0.44 |
| Timaru | 244 | 248 | 246 | 1873.95 | 1953.96 | 1913.955 | 0.04 | 0.54 | 0.46 |
| Wellington | 468 | 510 | 489 | 3021.12 | 3507.84 | 3264.48 | 0.08 | 0.60 | 0.40 |
| Whangarei | 287 | 325 | 306 | 2708.46 | 3184.62 | 2946.54 | 0.07 | 0.46 | 0.54 |

Table S6. A comparison of allocation weights for 13 ports in New Zealand, based on 2015-2016 vessel visit data. Numbers from this study were derived from our vessel biosecurity risk framework. Numbers from Hatami et al. (2021) were revised to include only 2015-2016 data for the 13 ports in common between the datasets.

| **Port** | **Hatami et al. (2021)** | **This Study** | **Their Ranks** | **Our Ranks** |
| --- | --- | --- | --- | --- |
| Tauranga | 0.233 | 0.212 | 1 | 1 |
| Auckland | 0.141 | 0.166 | 2 | 2 |
| Lyttelton / Christchurch | 0.106 | 0.100 | 3 | 3 |
| Napier | 0.094 | 0.088 | 4 | 4 |
| New Plymouth | 0.079 | 0.054 | 5 | 8 |
| Wellington | 0.067 | 0.076 | 6 | 5 |
| Nelson | 0.059 | 0.044 | 7 | 11 |
| Port Chalmers / Dunedin | 0.055 | 0.061 | 8 | 7 |
| Whangarei | 0.049 | 0.068 | 9 | 6 |
| Gisborne | 0.037 | 0.027 | 10 | 12 |
| Timaru | 0.036 | 0.044 | 11 | 10 |
| Bluff | 0.028 | 0.045 | 12 | 9 |
| Picton | 0.017 | 0.014 | 13 | 13 |